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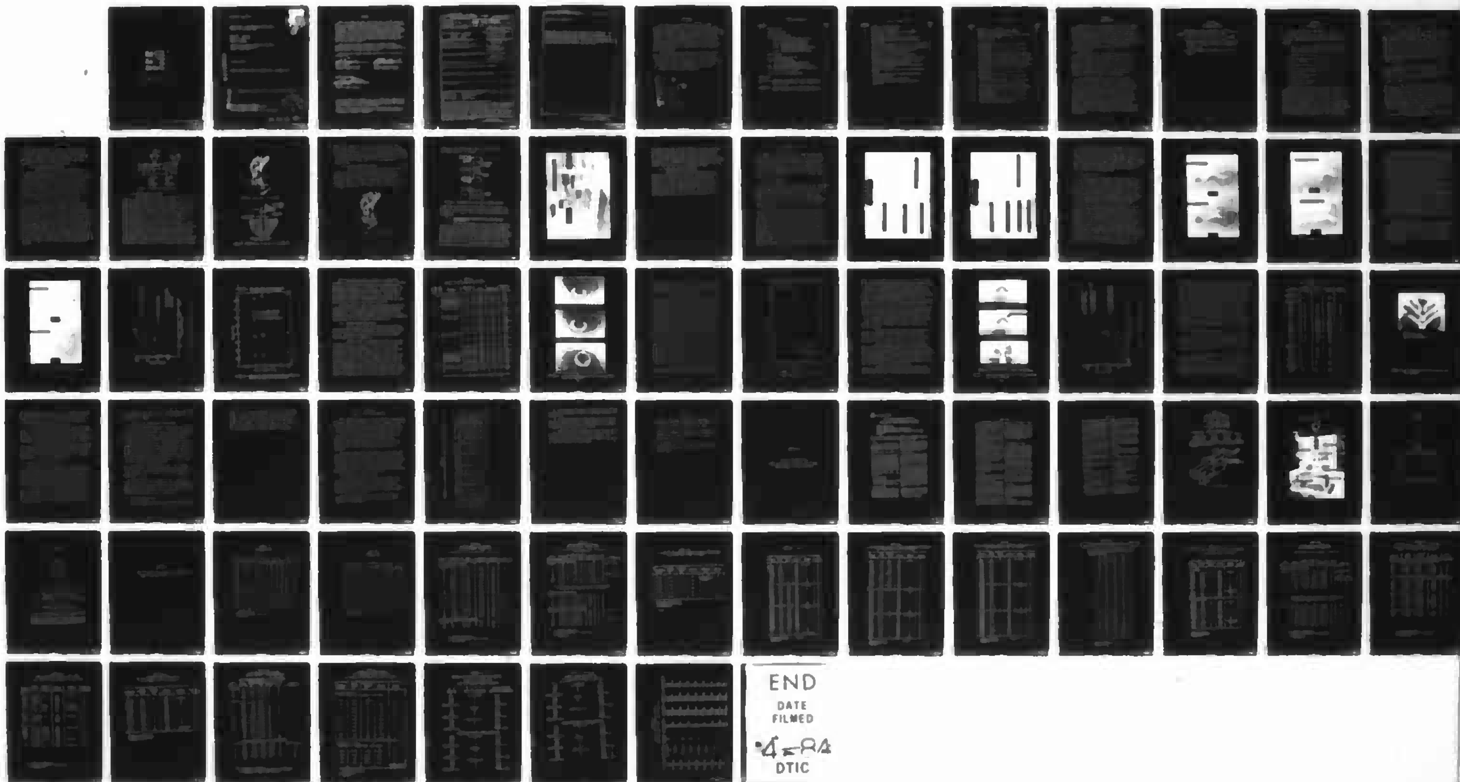

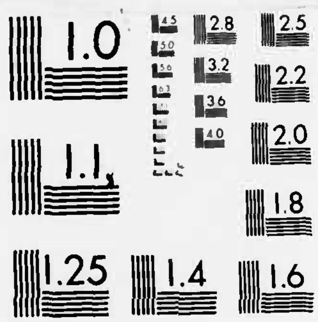

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DEVELOPMENT OF AN IMPACT RESISTANT TEST METHOD FOR POLYCARBONATE

Kenneth I. Clayton
Gregory J. Stenger
Blaine S. West
Paul E. Johnson

University of Dayton Research Institute
300 College Park Avenue
Dayton, Ohio 45469

February 1984

INTERIM REPORT FOR PERIOD OCTOBER 1978 - NOVEMBER 1983

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Robert J. Simmons

ROBERT J. SIMMONS
Program Manager
Advanced Development Branch
Vehicle Equipment Division

Wallace C. Buzzard

WALLACE C. BUZZARD
Chief
Advanced Development Branch
Vehicle Equipment Division

FOR THE COMMANDER

Solomon K. Metres

SOLOMON K. METRES
Director
Vehicle Equipment Division

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Polycarbonate offers many advantages as a structural transparency material, having excellent impact resistance as well as acceptable optical and thermal properties; however, one of the difficulties in evaluating impact resistance of polycarbonate is the lack of a universally accepted and standardized test method. Some transparency vendors rely on the falling weight impact test which yields good qualitative results. However, to date these falling weight impact tests have been performed under loosely controlled

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conditions, not governed by well-defined test procedures. The notched Izod test has been and continues to be used for qualitatively evaluating impact resitance of polycarbonate per MIL-P-83310, even though it has not been clearly established that this is the best method for evaluating the impact resistance of notch-sensitive polycarbonate. This report discusses six test methods and compares the results from each test.

FOREWORD

The effort reported herein was performed by the University of Dayton Research Institute, Dayton, Ohio, under Contract No. F33615-76-C-3103, Project 2202, entitled "Birdstrike Windshield Technology Program," and Contract No. F33615-80-C-3401, Project 1926, entitled "Birdstrike Resistant Crew Enclosure Program." This work was administered by the Air Force Flight Dynamics Laboratory, Wright-Patterson Air Force Base, Ohio, with administrative direction and technical support provided by Mr. Richard L. Peterson, Lt. Larry Moosman, and Lt. Robert Simmons, AFWAL/FIEA.

Project supervision and technical assistance was provided through the Aerospace Mechanics Division of the University of Dayton Research Institute with Mr. Dale H. Whitford, Supervisor, and Mr. Blaine S. West, Project Engineer. Testing was conducted in the UDRI Structural Test Laboratory by Mr. E. C. Klein and Mr. T. Helmick, and in the UDRI Impact Test Facility by Mr. C. Acton; all being major contributors.

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SECTION 1
INTRODUCTION

High performance Air Force aircraft are being fitted with transparencies utilizing polycarbonate (MIL-P-83310) material as the structural ply. In some designs, a single (monolithic) thick polycarbonate structural ply is used, especially when the number of ply interfaces is to be minimized for improved optics. In other applications, several thin polycarbonate and/or acrylic plies, separated by relatively low modulus interlayers, replace the monolithic construction. In either case, outer and inner surface protection may be provided by acrylic plies or protective coatings.

Polycarbonate offers many advantages as a structural transparency material, having excellent impact resistance as well as acceptable optical and thermal properties. The impact resistance of polycarbonate material is influenced by such parameters as thickness, temperature, ply configuration, processing procedures, surface finish, aging, and environmental exposure. In order to optimize the impact resistance of a candidate transparency design, the transparency designer must be able to evaluate the effect of these variables.

One of the difficulties in evaluating the impact resistance of polycarbonate (or change in impact resistance) is the lack of a universally accepted and standardized test method. Some transparency vendors rely on the falling weight impact test which yields good qualitative results. However, to date these falling weight impact tests have often been performed under loosely controlled conditions, not governed by well-defined test procedures. The notched Izod test has been used and continues to be used for qualitatively evaluating impact resistance of polycarbonate per MIL-P-83310, even though it has not been clearly established that this is the best method for evaluating the impact resistance of notch-sensitive polycarbonate.[1] Thus, no common basis exists for comparison of test results.

SECTION 2
PROGRAM OBJECTIVE

The objective of the experimental investigation conducted under this effort and documented herein is to:

- identify and evaluate potential test methods,
- develop a standard test method and procedure for evaluating the impact resistance of polycarbonate material, and
- make recommendations for application of that test method.

SECTION 3
EXPERIMENTAL APPROACH

3.1 SELECTION OF CANDIDATE TEST METHODS

In order to screen the most viable candidate impact resistance test methods for the experimental investigation, the following guidelines for meeting the program objective were developed.

- Strain rates to be representative of those attained during bird impact; providing the impact resistance of the test material is strain rate sensitive.
- Test results to be repeatable.
- Cost of testing apparatus, test specimen, and test time to be reasonable.
- Specimen configuration to be as simple as possible.
- Test method to be sensitive in detecting both gross and subtle changes in impact resistance.
- Test method to be adaptable to a wide range of material variables.
- Test sample failure mode(s) to be relevant to those encountered in service.

The optimum test method will consider all the above requirements, but must contain compromises due to practical constraints. The following paragraphs present a summary of advantages and disadvantages of the candidate test methods which were selected from a review of industry and ASTM test methods currently being employed, namely: air cannon, falling weight, notched Izod, notched Charpy, high rate simply-supported three-point flexure, and high rate tension. For this program, emphasis was placed on falling weight impact testing of 0.250 and 0.31 inch thick uncoated polycarbonate plates with spot checks made on 0.125 inch uncoated, 0.125 inch coated, and 0.125 inch thermal cycled; 0.31 inch coated and 0.31 inch thermal cycled; and 0.5 inch plates.

3.1.1 Air Cannon Test Method

An air cannon test offers the greatest potential for providing the most realistic impact loading of the test sample. High strain rates can be generated at specialized test facilities. The test sample size, type, and mounting configuration can be configured to simulate a representative test condition. The impactor velocity and configuration are usually capable of some adjustment so that the total impact energy and energy distribution can also be adjusted to match the desired test condition. The air cannon test method has the highest cost per test, especially if a significant amount of instrumentation is used. Test results are usually qualitative in nature and relatively large amounts of material are required.

The 1-1/2 inch bore cannon installed at the UDRI Dynamic Mechanics Gun Range was used in the program. The cannon can be operated on compressed air or a powder charge. The gun itself is a 6-foot long, 1-1/2 inch I.D., heavy wall tube supported on a heavy I-beam. A vent section is connected to the muzzle of the gun to release the driving pressure from the back of the projectile package.

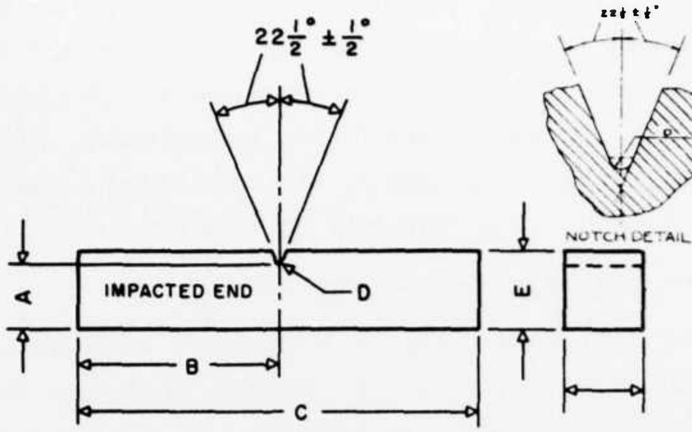
Projectiles are placed in a sabot, or carrier, for launching; the sabot being a 1-1/2 O.D. Lexan cylinder. Since the sabot represents a significant fraction of the launch mass, it must be stripped from the projectile before the projectile impacts the target. Therefore, a sabot stripping section is connected to the muzzle end of the vent section. When the launch package enters the sabot stripper section, the sabot is progressively decelerated until it stops; the projectile continuing on trajectory to the target. Velocities up to 3000 ft/sec are possible with this gun which can result in strain rates of over 10,000 in/in/sec.

Air cannon range facilities are complemented by an extensive range of high speed instrumentation, enabling resolution of even the most transient impact events. Equipment on hand includes high speed framing cameras (up to 4.5 x 10^6 fps), high speed streak cameras, flashed x-ray equipment (10 channels), laser velocitometry, high power pulsed laser holography, high speed digital data acquisition equipment (10 channels), and seven oscilloscopes ranging up to 500 MHz bandwidth.

3.1.2 Falling Weight Test Method

The falling weight test method, ASTM Method F736-81, has several advantages over the air cannon method with one disadvantage--lower impactor velocities. An air cannon facility typically produces impact velocities at least an order of magnitude above falling weight velocities (falling weight velocities being approximately 25 to 34 ft/sec corresponding to drop heights of 10 to 18 feet, respectively). However, a falling weight test apparatus is much less costly to construct/operate and easier to instrument in any attempt to generate quantitative data. Specimen fabrication is relatively straightforward for this method. Numerous falling weight facilities are in existence, but the associated test hardware and test procedures vary widely.

The UDRI Falling Weight Impact Test Apparatus is shown as Figure 1 of Appendix A. This tester will accommodate simply supported or clamped plate specimens (Type "A" specimens) of various span/thickness ratios, as well as simply supported beams (Type "B" specimens) of varying span/thickness ratios. A lifting carrier is provided to raise or lower the impactor to a maximum drop height of 20 feet. Hemispherical impactors of one-quarter-, one-half-, one-, one-and-one-half-, and two-inch diameter are available and interchangeable for impact testing of plates. An impactor loading nose and adjustable supports are available for three-point impact testing of simply supported beams. Drop weights are detachable, interchangeable, and variable in known increments from one pound to a total of 50 pounds. A two-cable system guides the falling weight to strike the center of the specimen at an impact velocity approaching free fall. Automatic release and rebound catch mechanisms are provided.



	mm	in.
A	10.16 ± 0.05	0.400 ± 0.002
B	32.20	1.260
	31.50	1.240
C	63.50	2.500
	60.30	2.375
D	0.25R ± 0.05	0.010R ± 0.002
E	12.70 ± 0.15	0.500 ± 0.006

Figure 1. Notched Izod Test Specimen.

3.1.3 Notched Izod Test Method

The standardized notched Izod test method (ASTM D256-73, Method A) yields qualitative results, but requires a test sample with a critical machining operation (notching) as shown in Figure 1. Attempts have been made to quantify this test method but as yet an ASTM standard has not been generated which relates the impact strength energy to the material properties. The specimen is clamped in a vertical position in a vise using fixturing to precisely locate the notch in reference to the test frame. Figure 2 presents a sketch of the Izod impact machine. The striking nose of the pendulum strikes the sample at an initial velocity of 11.4 ft/sec at a point 0.866 inches above the notch. The side of the specimen with the notch faces the impactor as shown in Figure 3. One result of notching is an effective increase in the strain rate of the material; hence the geometry of the notch and the method of fabrication must be carefully controlled to ensure the validity of the test. The energy expended in deforming or fracturing the specimen is calculated by deducting the values for the residual energy in the pendulum and losses due to friction and windage in the apparatus from the initial

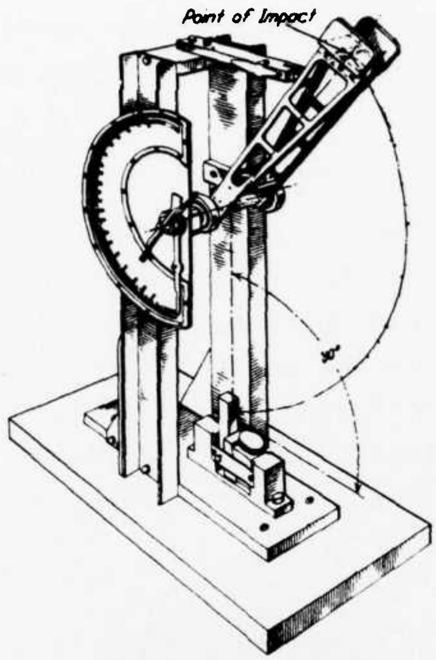


Figure 2. Izod Impact Test Machine.

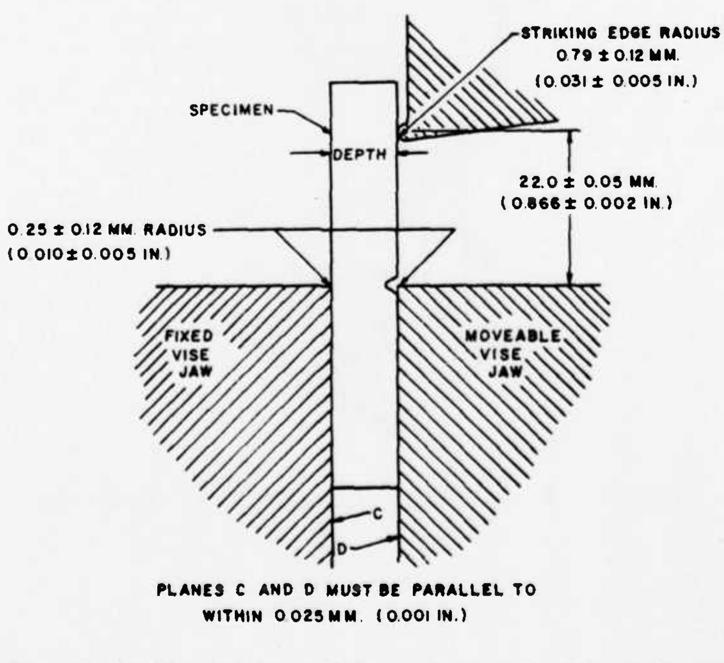


Figure 3. Relationship of Specimen to Izod Impactor.

energy to the pendulum. In the case of sheet material, the direction of laoding is in the plane of the material and perpendicular to the direction of rolling unless the direction of loading is a variable in the test matrix. In comparison with the air cannon and falling weight methods, the size of the specimen for the notched Izod method is much smaller and the cost of the apparatus is typically less.

3.1.4 Notched Charpy Test Method

The notched Charpy test method (ASTM D256-73, Method B) is very similar to the notched Izod method. The Charpy test specimen is loaded in simply supported three-point fiexure as opposed to the fixed cantilever beam loading employed in the Izod test method. Both tests use the same test machine, utilizing different supports and impactor heads (reference Figure 4). In the notched Charpy test, the impactor loading nose strikes the

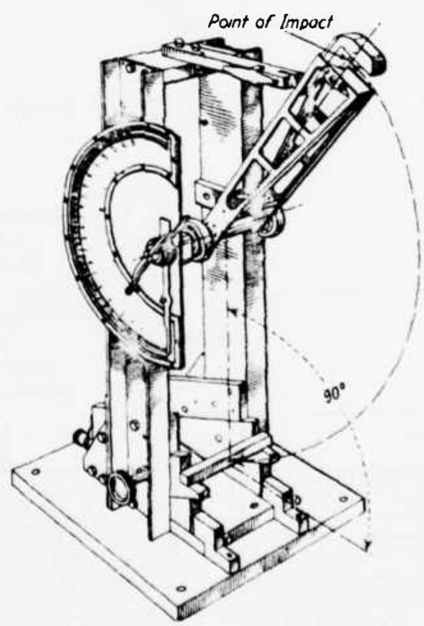


Figure 4. Charpy Impact Test Machine.

specimen directly behind the notch as shown in Figure 5, and the support span is 3.75 inches.

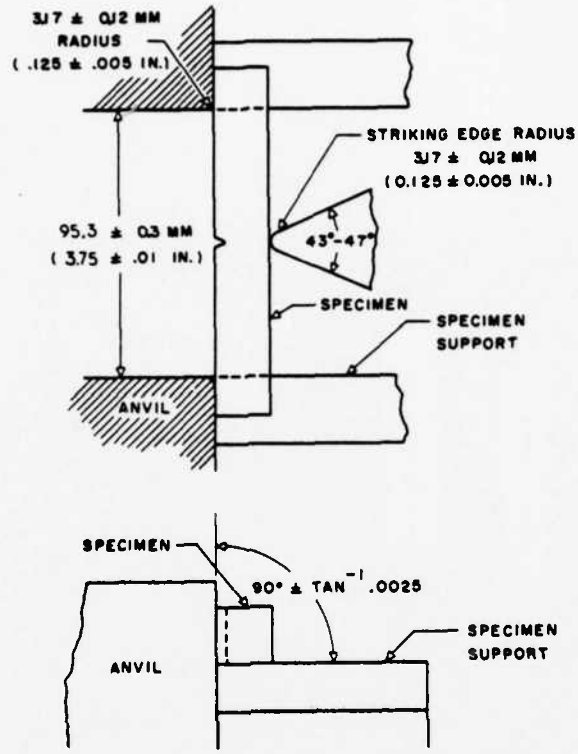


Figure 5. Relationship of Specimen to Charpy Impactor.

In both tests, the impactor velocity decays as the specimen is deformed or fractured, the amount of decay being dependent upon the energy of the impactor, and the rate of energy absorption in the specimen.

3.1.5 High Rate Simply-Supported Three-Point Flexure Test Method

For this test method, the high-rate simply-supported three-point flexure test specimen and supports are per ASTM D790-71 Method I with a 16/1 span-to-depth ratio. The test displacement rate, however, is much higher with high-performance electrohydraulic, servo-actuated MTS System Corporation closed loop testing equipment such as that shown in Figure 6. Ram velocities of 60,000 in/min (69.4 ft/sec) are attainable for displacements up to five inches. The direction of loading is transverse instead of longitudinal as in the Charpy test; otherwise this type of test is similar to an

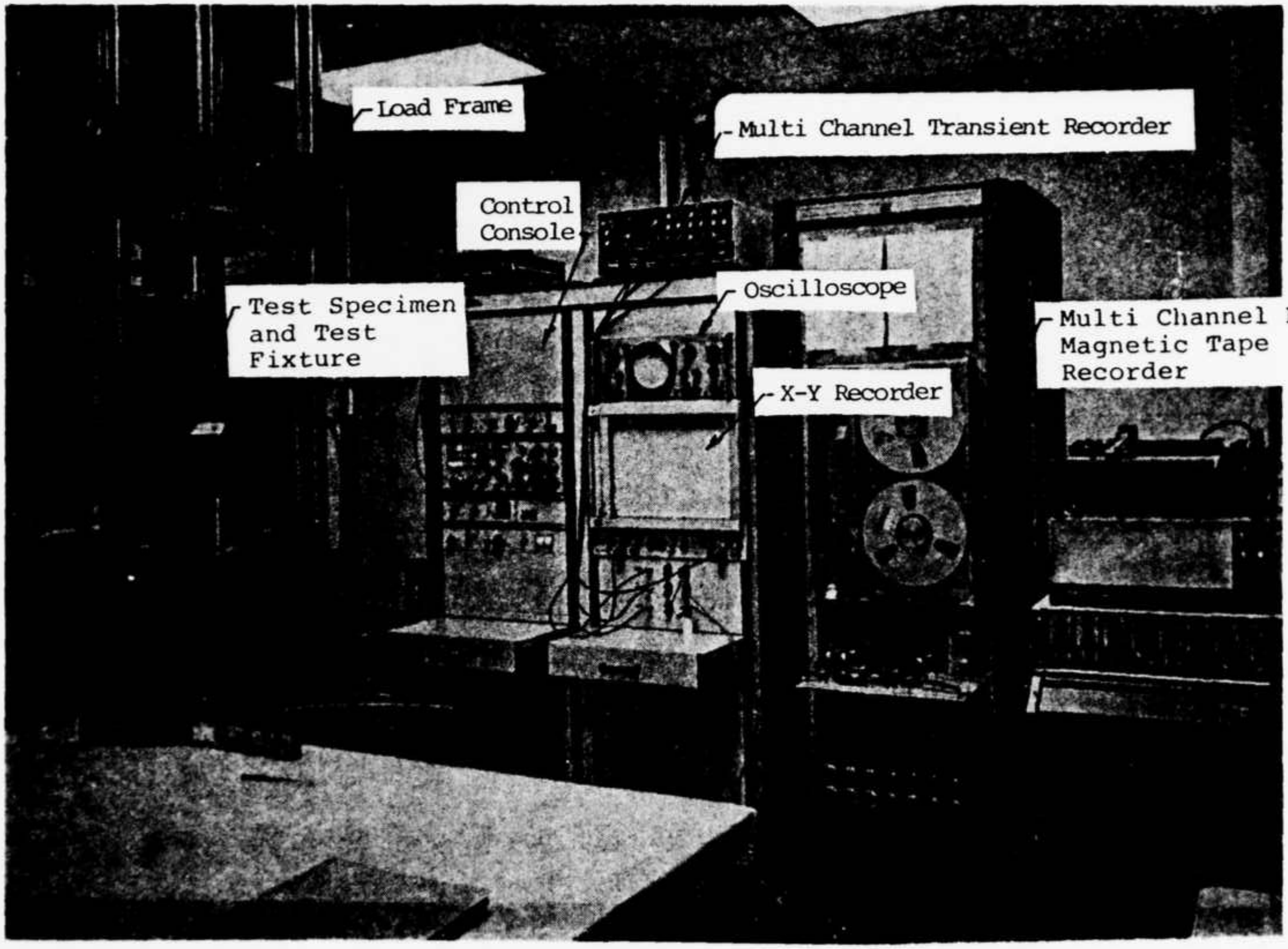


Figure 6. High Performance Electrohydraulic Closed-Loop Test System.

unnotched Charpy test. The test velocity is constant during the test and does not decay as with previously discussed methods. Test data is repeatable and more quantitative than previously discussed methods, which enables a breakdown of the test data into sections of elastic deformation and plastic deformation or fracture propagation and a determination of attendant mechanical property values. The relative cost of the apparatus is high.

3.1.6 <u>High-Rate Tension Test Method</u>

High-rate tensile tests per ASTM 1822-68 can be conducted, using appropriate fixturing, in the same impact test machine used for Izod and Charpy tests, and produce strain rates of about 2.5 in/in/sec. High-rate tensile tests can also be conducted in a high performance electrohydraulic test machine (reference Figure 6) per ASTM 2289-69; this method results in strain rates of more than 1600 in/in/sec. As in the case of high-rate flexure tests, the latter test method will generate quantitative test data, but the cost of the apparatus is high.

SECTION 4
TEST PROGRAM

The test program consisted of 31 air cannon tests, 402 falling weight tests, 30 notched Izod tests, 30 notched Charpy tests, and 39 simply-supported three-point flexure tests. No high rate tests were conducted because of the limited funds available for this program. Typical failed specimens are shown in Figures 7 and 8 illustrating the relative specimen size as specified by the associated test method. The following paragraphs describe the test specimen material, the test procedures used, and present the test results.

4.1 TEST SPECIMEN MATERIAL

The test samples for the experimental program were fabricated from three different types of monolithic polycarbonate: SL-3000 G.E. Lexan® per MIL-P-83310 in two thicknesses, nominal 0.125 inch and 0.310 inch, both coated (FX-103 coating, one side) and uncoated; Rohm and Haas Tuffak®, uncoated, per MIL-P-83310, nominal thickness 0.310 inch; and commercial grade Lexan® (9030 Series) in two thicknesses, nominal 0.250 inch and 0.500 inch. The 0.46 inch stretched acrylic (MIL-P-25690) was included for comparative purposes.

Tests were conducted on the SL-3000 at three different material conditions for each thickness to evaluate the sensitivity of the test methods to typical processing variables. The 'AR' (As-Received) condition was produced by storing the incoming material in the laboratory environment (73±2°F, 50±5% R.H.) at least four weeks prior to testing. The 'C' (coated) condition was procured with a coating (FX-103) known to severely embrittle polycarbonate, applied to one side of the sheet, followed by a minimum of four weeks storage in the laboratory prior to testing. The 'TC' (Thermally Cycled) condition was produced by placing the finish machined samples in a preheated air-circulating Instron heating chamber at 105°C (257°F) for two hours (typical fabrication heat treatment temperature), followed by air cooldown to room temperature for one hour followed by immediate testing.

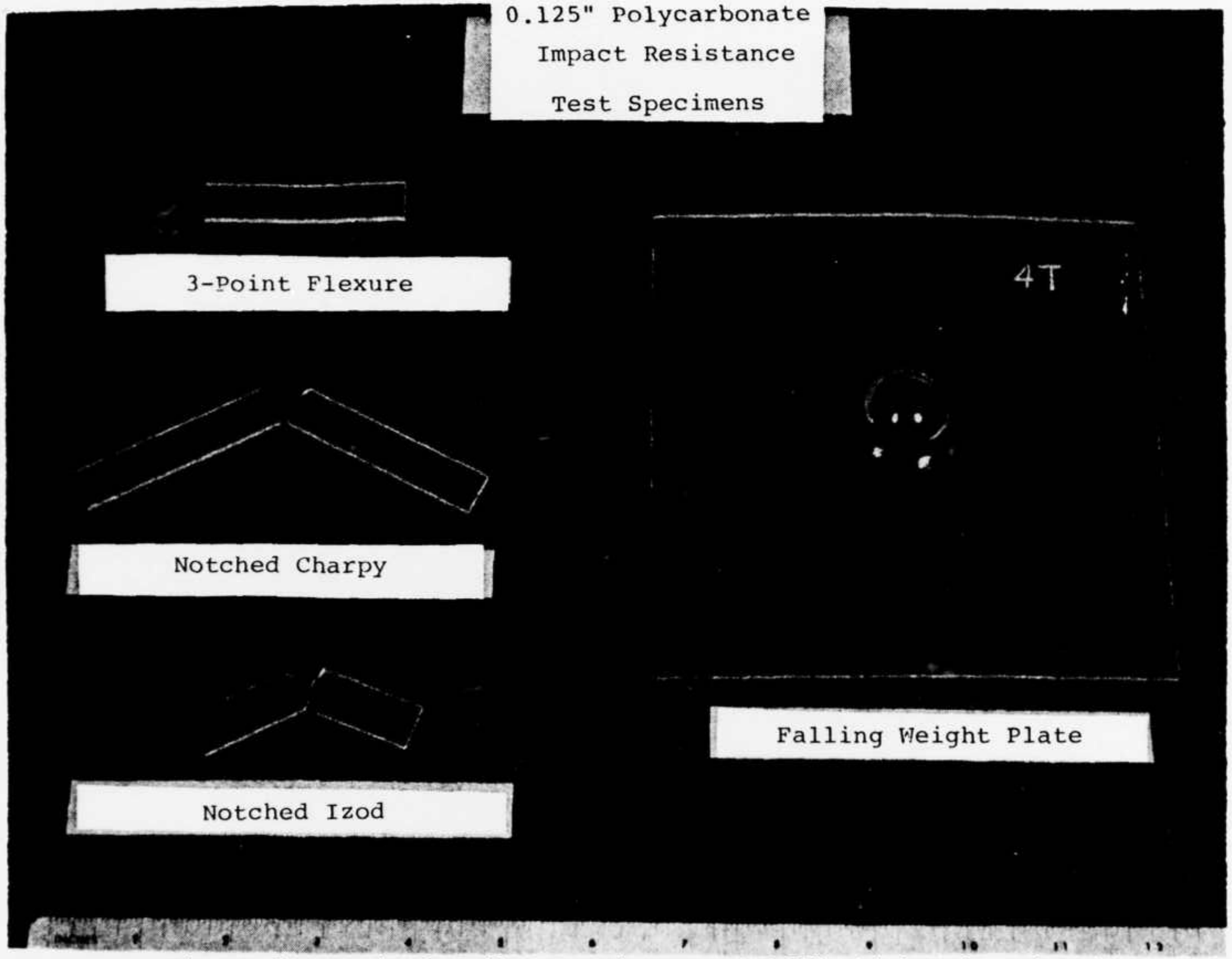


Figure 7. Typical Failed Specimens - 0.125" Thick Polycarbonate.

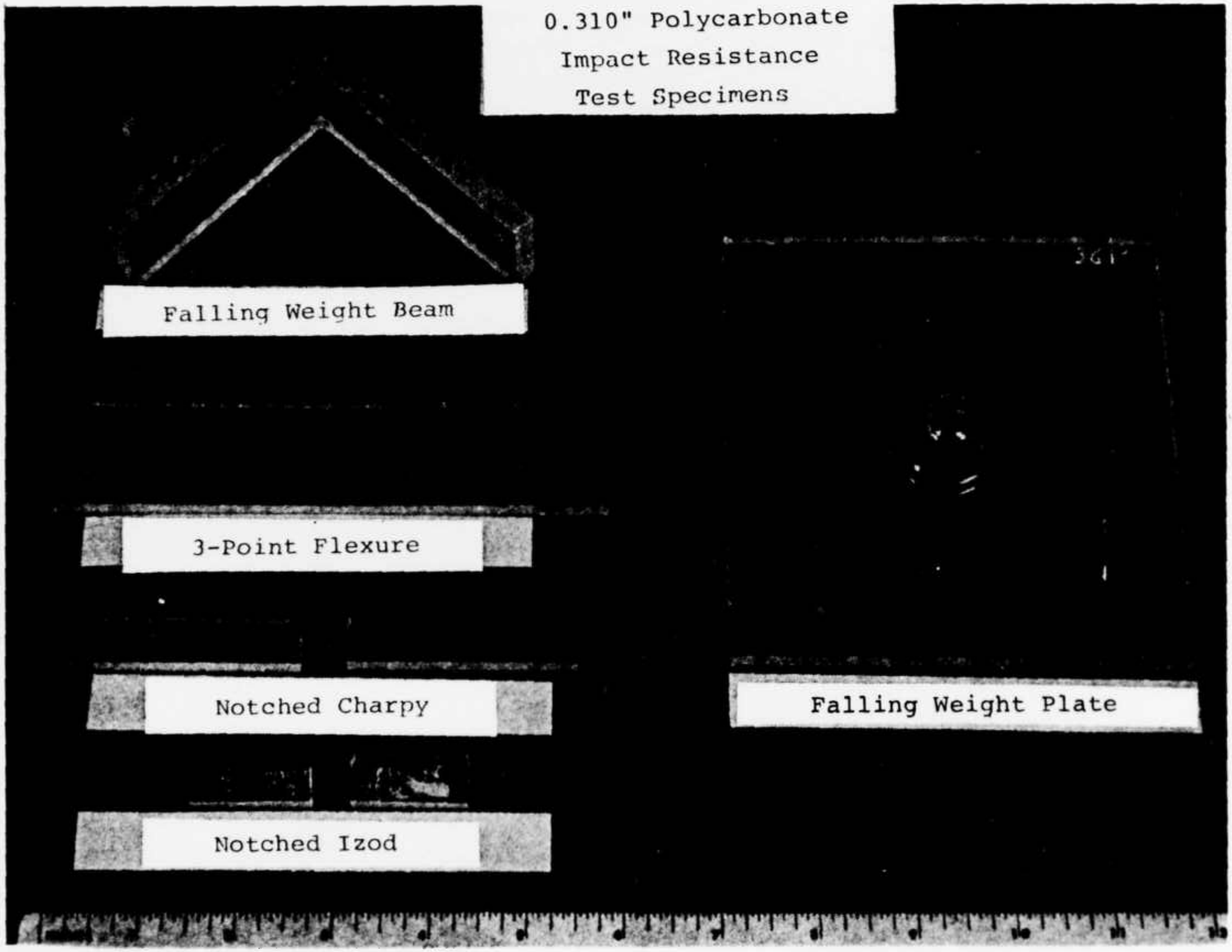


Figure 8. Typical Failed Specimens - 0.310" Thick Polycarbonate.

The Rohm and Haas Tuffak and the commercial grade G.E. Lexan materials were tested in the AR condition only. In the case of the AR, TC, and C conditions, the beam samples were machined from the conditioned material using techniques developed to produce a minimum of residual stress, and all of these samples were inspected photo-elasticially to verify the absence of fabrication induced residual stresses.[2] Falling weight and air cannon plate test specimens were bandsawed to size because the edge condition was not critical (Reference 3 and Appendix A).

4.2 AIR CANNON TESTS

A total of 31 air cannon tests were conducted on uncoated monolithic polycarbonate to evaluate the effects of high strain rate impact. These tests are compared to falling weight tests in Section 4.3. The 12 x 12 inch plate specimens, in two thicknesses, were mounted with simply supported edge conditions on a 10 x 10 inch steel frame. The plates were then impacted in the center using either a spherical (66.7 gm) projectile or a bullet shaped (287 gm) projectile. The two impactors were used to study the effect of impactor velocity on threshold-of-failure energy (minimum energy required to form a visible open crack).

The results of 16 air cannon tests conducted on 0.31 inch thick uncoated polycarbonate are presented as Table B.1 in Appendix B. The 1.0 inch diameter spherical impactor produced a failure threshold of about 975 ft-lbs for the G.E. Lexan. The bullet impactor (a 1.0 inch diameter cylinder, 2-1/2 inches long, with a hemispherical nose, total length of 3 inches) produced a failure threshold of about 1170 ft-lbs in the G.E. Lexan, a 20% increase in failure energy at 53% of the spherical impactor velocity. Figures 9 and 10 show typical 0.31 inch thick specimens after testing. These specimens were photographed on graph paper (note the distortion around the impacted area). The impactor is shown off to the side.

Table B.2 in Appendix B presents the results of 15 tests conducted on 0.5 inch thick commercial grade G.E. Lexan. The failure thresholds were 1740 ft-lbs with the spherical impactor

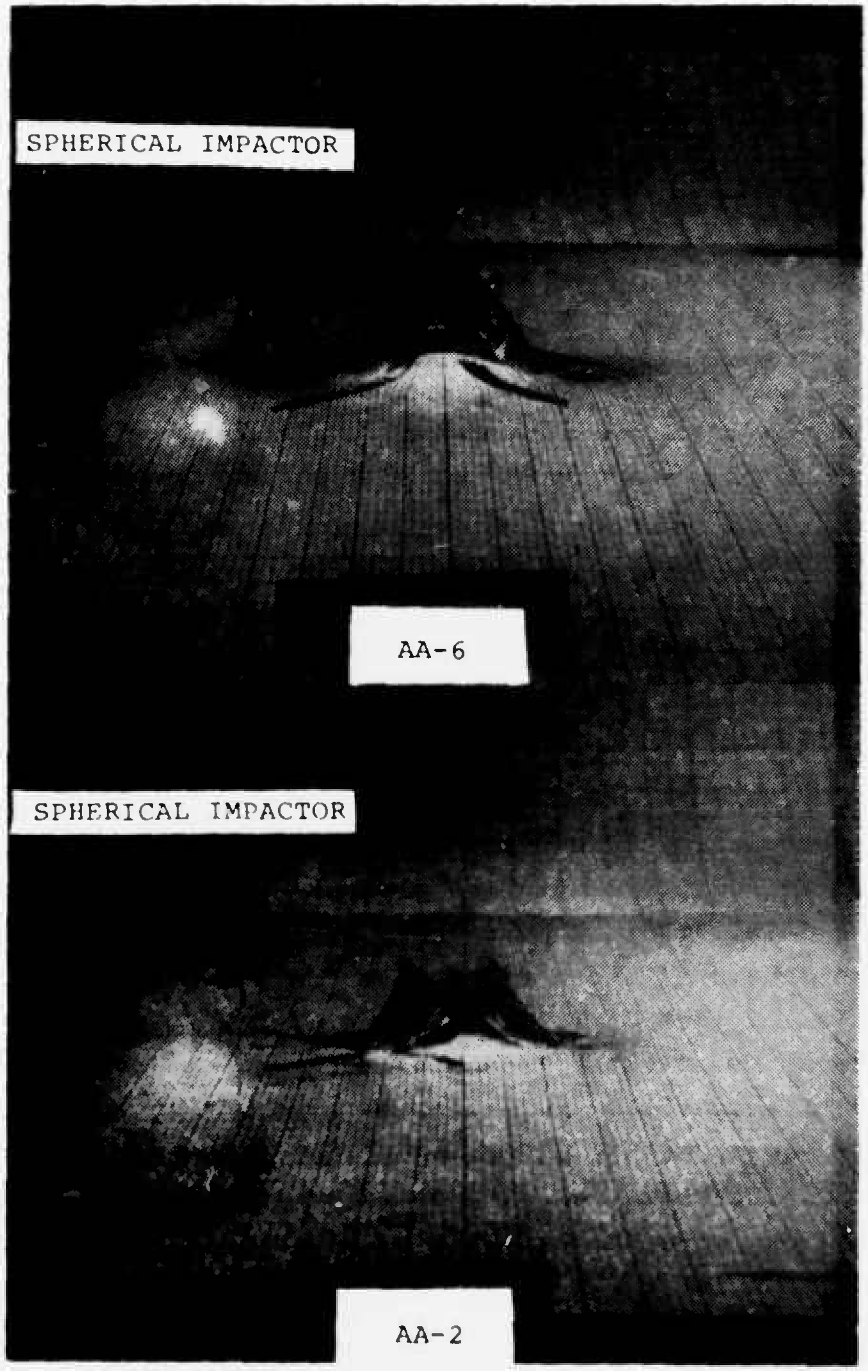


Figure 9. Typical .31 inch Thick Tested Specimen.

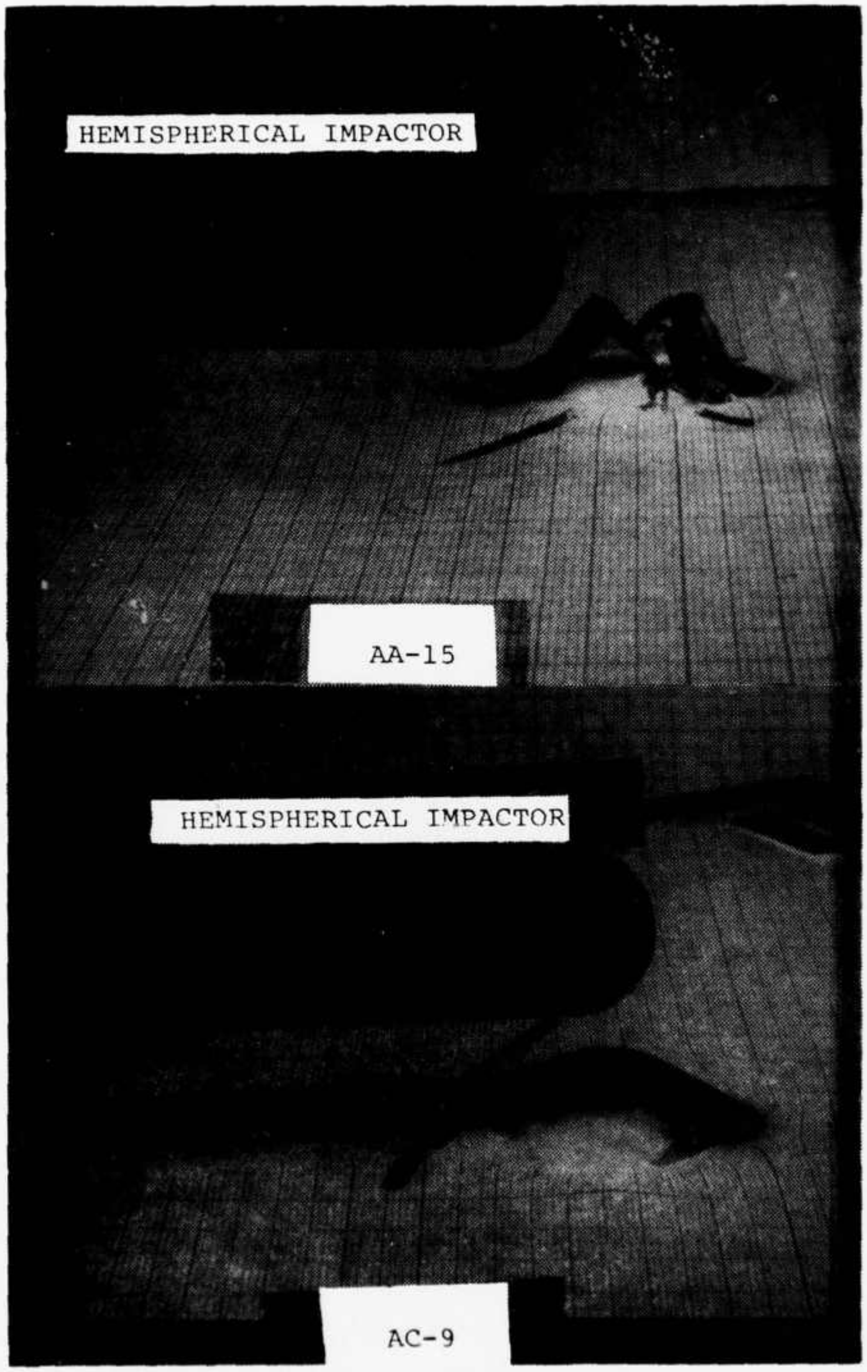


Figure 10. Tests Made with Bullet Impactor.

and 2090 ft-lbs with the bullet impactor--a 20% increase in failure energy over the spherical impactor. The velocity of the bullet impactor was 52% of the velocity of the spherical impactor at the failure threshold, the same relative difference as in the previous tests. This indicates that the relative differences between the threshold of failure for the two impactors may not have been directly related to the material thickness. The material was 60% thicker and the velocities were over 30% higher in the second series of tests, yet the relative difference in failure threshold between impactors remained unchanged. Figure 11 shows typical 0.5 inch thick specimens impacted with a spherical impactor.

An unexpected result was the apparent decrease in the impact strength at the higher impact velocities as shown in Figure 12. The relative difference (20%) between the threshold of failure energies for the spherical and bullet impactors may have been due to any combination of several factors which include differences in impactor geometry and surface finish, as well as differences in velocity (higher velocities may result in more localized straining of the material) and material thickness. Falling weight data was included in this plot for comparison. The fact that the span was different between the falling weight (8 inch diameter span) and the air cannon (10 inch square span) is not expected to have a significant effect on this comparison (see Figure 13). A better understanding of the strain rate effects in polycarbonate is needed.

4.3 FALLING WEIGHT TESTS

A total of 402 falling weight impact tests were conducted in accordance with ASTM Method F736-81; 391 tests were conducted on monolithic polycarbonate specimens to determine the effects of impactor size, impactor configuration, impactor finish, specimen configuration, support span, material thickness, material conditioning, and impactor velocity; and 11 tests were conducted on monolithic stretched acrylic to compare its impact resistance to that of polycarbonate.

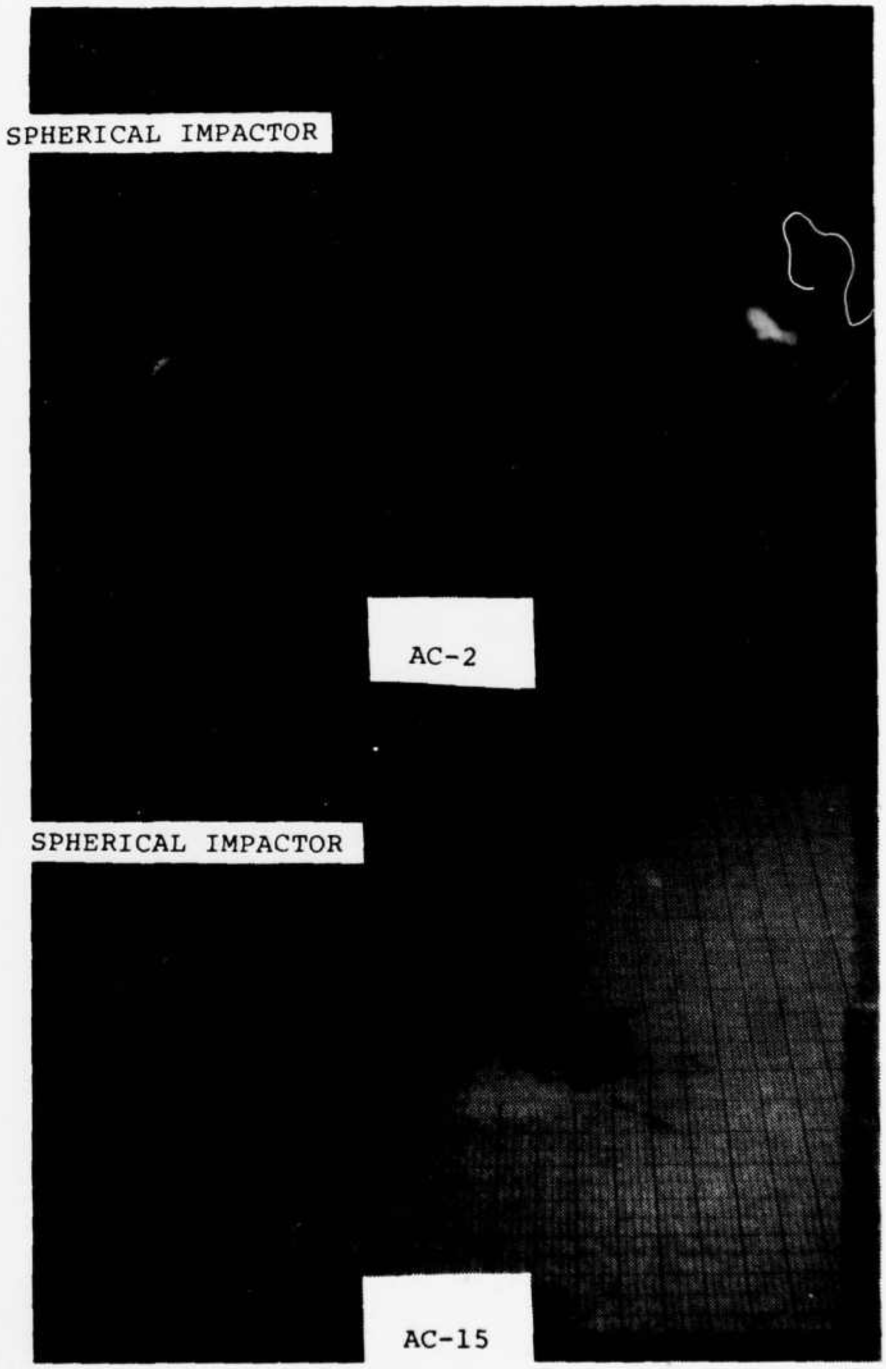


Figure 11. Typical .50 inch Thick Tested Specimens.

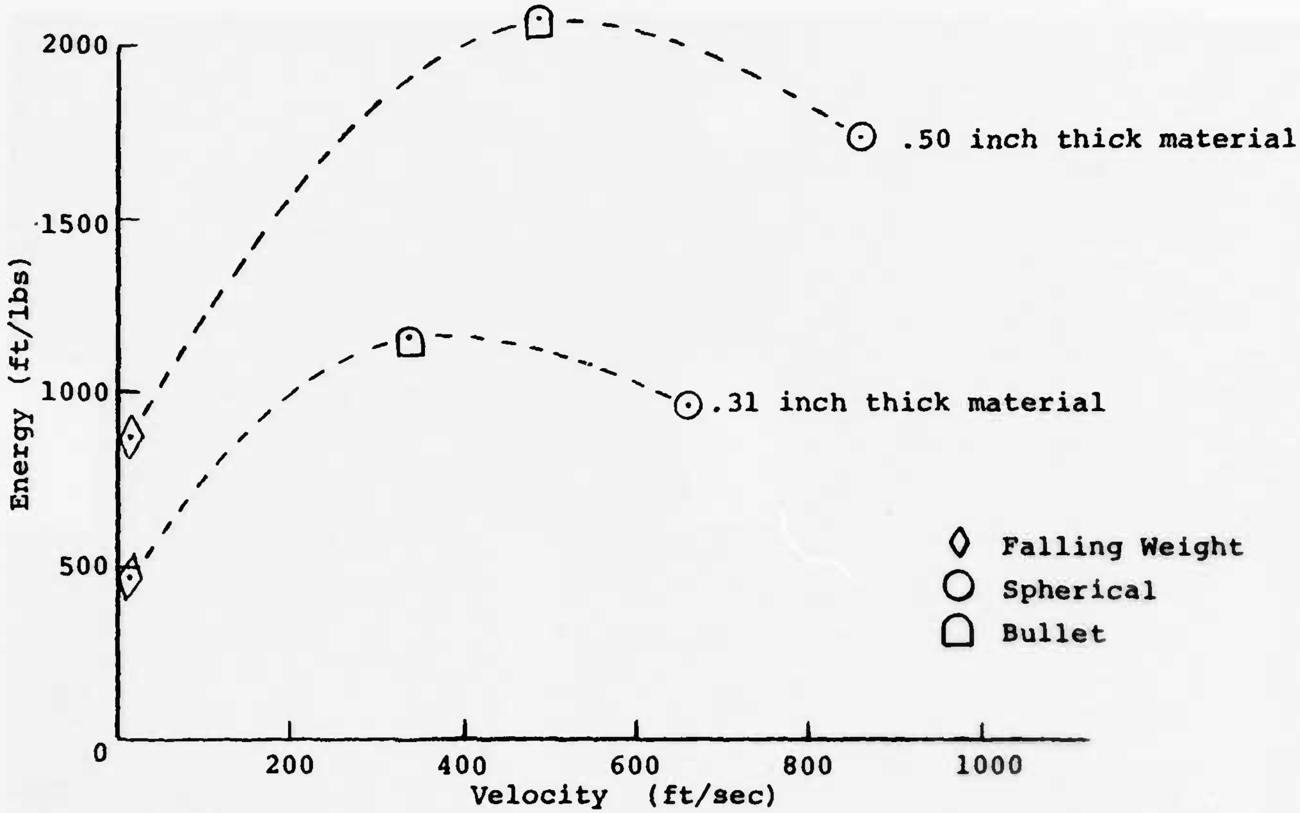


Figure 12. Threshold Energy Plotted as a Function of Velocity.

Material: .250 inch thick Commercial Grade Polycarbonate (G.E. Lexan®)

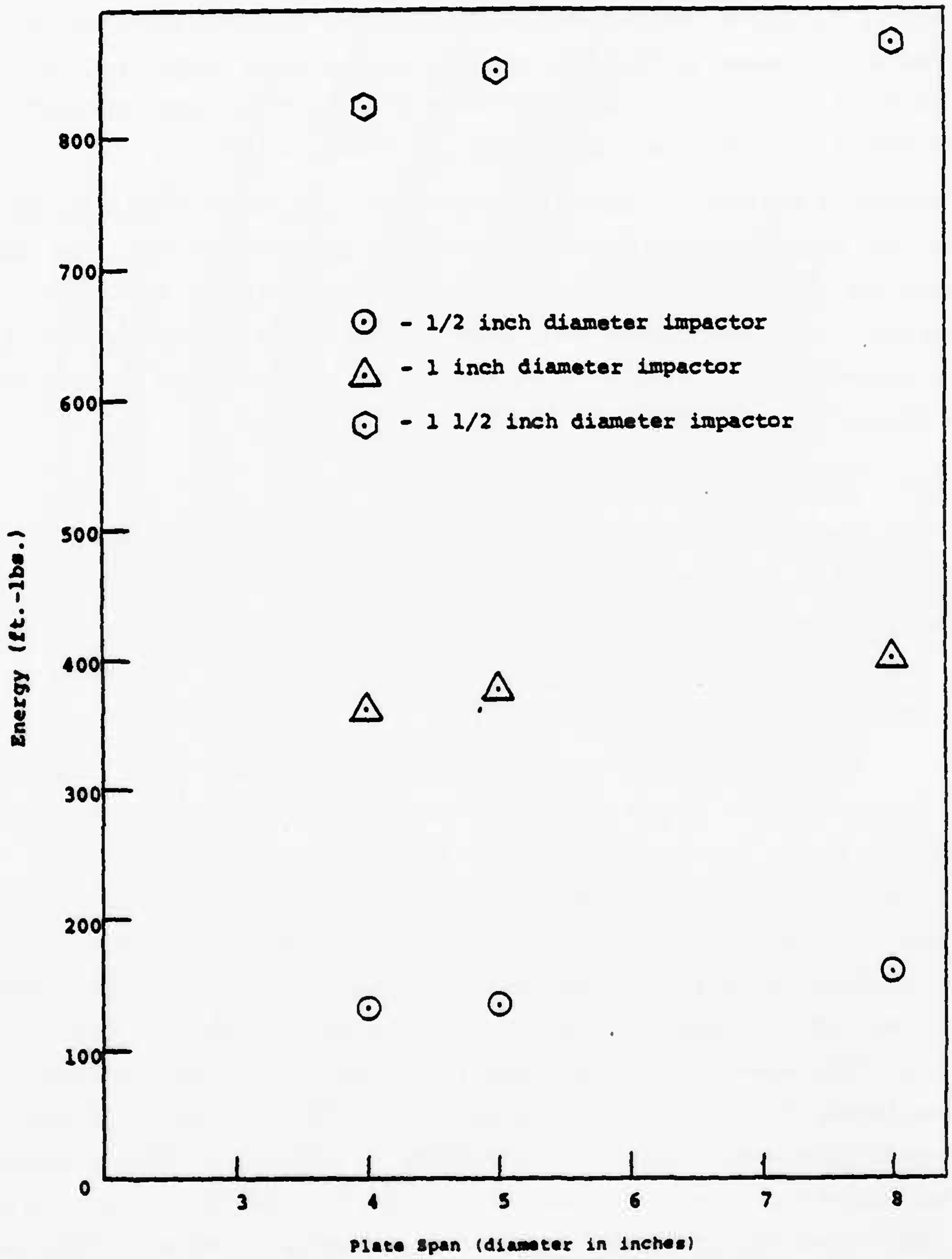


Figure 13. Effects of Plate Span on the Failure Threshold Energy (Falling Weight Test Results).

Using five different sizes of hemispherical impactors, 363 Type "A" plate specimens were mounted in a clamping ring setup and tested. The results of the plate tests are presented and summarized in Paragraph 4.3.1 and Table 1. Thirty-nine Type "B" beam specimens were tested using an impactor nose and supports corresponding to ASTM Method F736-81 (D790-I). The results of 28 polycarbonate beam tests are presented in Paragraph 4.3.2 and Tables B.15 and B.16. The results of eleven tests conducted on stretched acrylic beams are included in Table B.16.

Although limited in number, the tests performed did indicate trends in the behavior of impacted polycarbonate and enabled the recommendation of an economical standard test method for ASTM consideration. The standard was adopted as ASTM Method F736-81, "Standard Practice for Impact Resistance of Monolithic Polycarbonate Sheet by Means of a Falling Weight" (see Appendix A).

4.3.1 Falling Weight Plate Tests

Falling weight plate tests have been conducted on 363 polycarbonate specimens using nine different impactors, three plate spans, four material thicknesses, and three material conditions. Specimens were mounted in accordance with the ASTM F736-81 test method (see Appendix A).

Tables B.3 and B.4 (Appendix B) present the results of tests conducted on 0.125 inch thick material; typical tested specimens are shown in Figure 14. A total of 33 tests were conducted on uncoated polycarbonate, and 11 of these specimens were thermal cycled at 257°F. Based on the test data, the estimated failure threshold for the specimens in the as-received condition was 185 ft-lbs for the 4.96 inch span and 200 ft-lbs for the 8.0 inch span. The failure threshold for the thermally cycled specimens with a 4.96 inch span was 155 ft-lbs. Of the eight coated specimens tested, four were tested with the coated side in compression (up) and four with the coated side in tension (down). The results of these tests demonstrated the embrittling effect of a surface coating. The failure energy for the tests

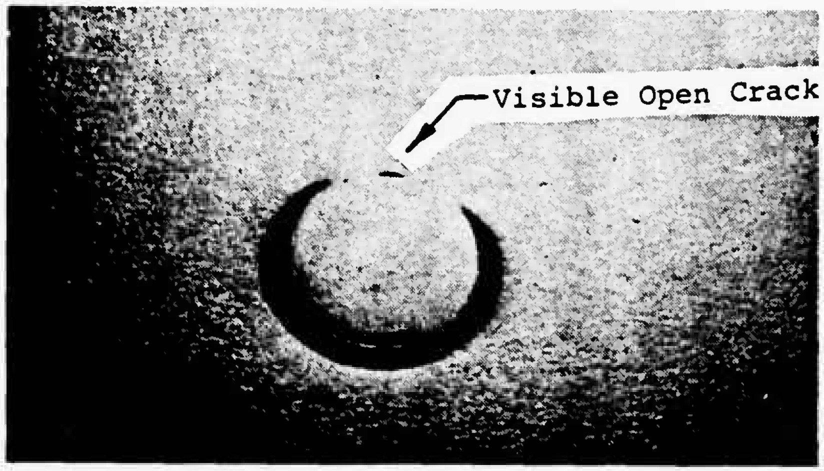
TABLE 1

RESULTS OF FALLING WEIGHT-PLATE TEST

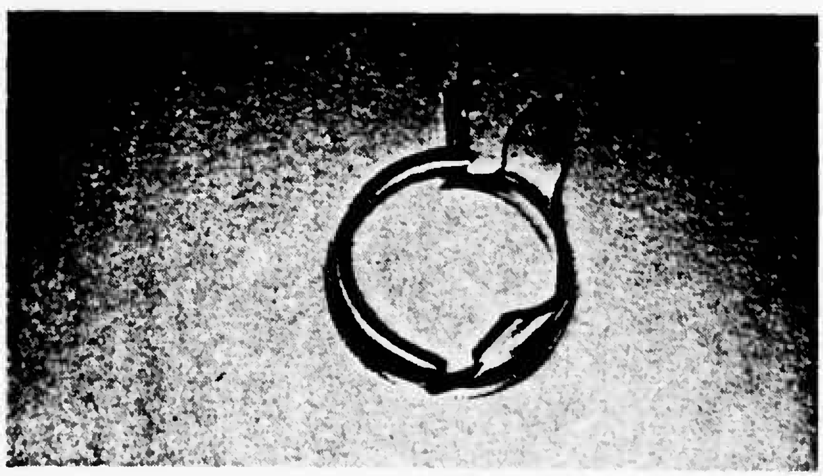
Material Thickness (in.)	Material Type	Impactor Size (in.)	Span Dia. (in.)	Number of Specimens*	Threshold Energy (ft-lbs.)
.125	Mil-Spec Lexan	1	4.96 8.0	11 11	185 205
	Thermal-Cycled	1	4.96	11	155
	Coated Side Up	1	4.96	4	60
	Coated Side Down	1	4.96	4	5
.25	Commercial Lexan	¼	4.0	6	45
		1	8.0	10	400
		1½	8.0	18	875
	Mil-Spec Lexan	½	4.0 4.96 8.0	14 21 18	135 135 160
		1	4.0 4.96 8.0	15 17 8	380 390 410
		1½	4.0 4.96	18 17	835 825
.31	Mil-Spec Lexan	½	4.0 4.96 8.0	5 4 6	175 180 200
		1	4.0 4.96 8.0	37 31 6	475 500 575
		1-polished	4.0 4.96	5 6	500 475
		1-stainless	4.96	5	500
	Coated Side Down	1	4.96	6	20
	Thermal-Cycled	1	4.96	8	470
	Mil-Spec Tuffak	1	4.0	13	475
		1-polished	4.0	5	500
.50	Commercial Lexan	1	4.96	15	860
		1-polished	4.96	2	>900

* Results of tests on six specimens are not included in this table.

Typical Ductile Deformation Prior to Failure



Typical Failure Threshold



Typical Penetration Beyond the Failure Threshold

Figure 14. 0.125" Thick Uncoated MIL-P-83310 Polycarbonate Plate Test Specimens.

conducted with the coating in compression was 135 ft-lbs and for the specimens tested with the coating in tension the failure energy was only 6 ft-lbs. These tests demonstrate the usefulness of the falling weight tests in qualitatively evaluating the relative impact strength of a material.

Tables B.5 through B.8 summarize the tests conducted on 0.25 inch thick commercial grade polycarbonate (Lexan) in the as-received condition. The tests were conducted to evaluate the effects of impactor size, plate span, and impactor velocity on the threshold of failure energy. Five impactors with diameters of 1/4, 1/2, 1, 1-1/2, and 2 inches, and three plate spans with diameters of 4.00, 4.96, and 8.00 inches were used. Tables B.5 and B.6 present the results of 54 tests conducted on specimens supported with a 4-inch diameter span and impacted with one of the five different size impactors. The 2-inch diameter impact tests were discontinued because the required energy levels for failure exceeded the test equipment capability. The 55 test results for specimens tested with a span of 4.96 inches are presented in Table B.7. Tests conducted using the 1/2 inch diameter bullet investigated the effect of varying the velocity a small amount by changing the drop height and falling weight. The velocities varied from 17 ft/sec to 31 ft/sec, with no measurable change in the threshold energy. The results of 54 tests conducted using the 8.0 inch span have been presented in Table B.8. Threshold of failure energies fell within a $\pm 7\%$ band. Figure 13 shows energy as a function of plate span for three different size impactors. The energy increases only a small amount for relatively large increases in plate span. Figure 15 shows energy as a function of impactor size for the three different plate spans. The energy appears to increase at an increasing rate with greater impactor diameters.

One hundred forty-two tests were conducted on 0.31 inch thick coated and uncoated polycarbonate; the results of the tests are presented in Tables B.9 through B.13 (Appendix B).

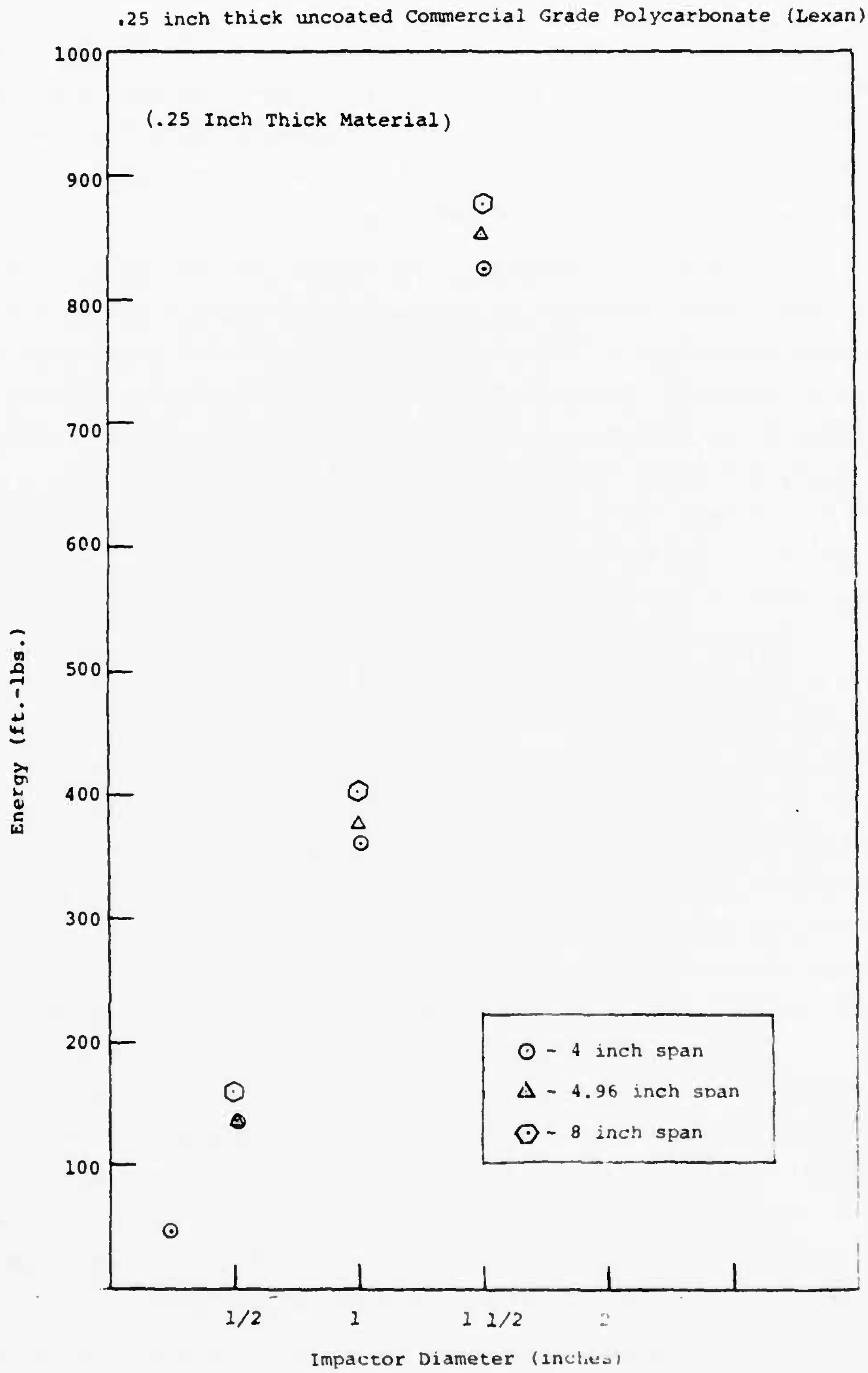


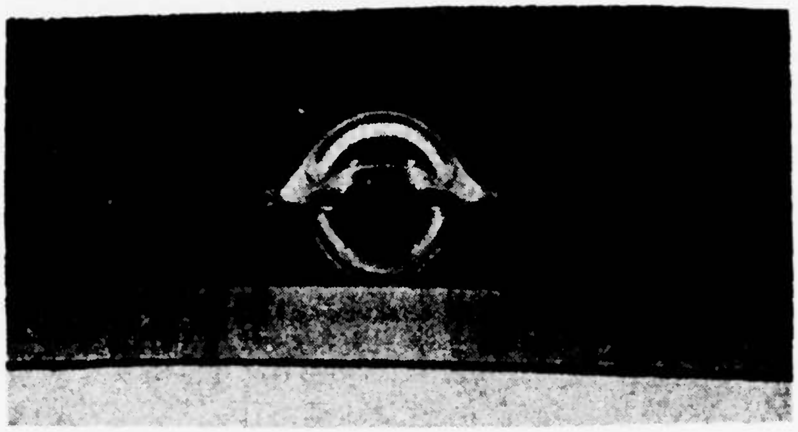
Figure 15. Effects of Impactor Size on the Failure Threshold Energy.

Typical tested specimens are shown in Figure 16. The results of tests conducted on MIL-P-83310 uncoated polycarbonate are presented in Table B.9 and a comparison is made in Table B.10 between the MIL-P-83310 G.E. Lexan and the Mil-P-83310 Rohm & Haas Tuffak. The results of tests conducted on coated specimens are presented in Table B.11 and show the embrittling effect of a surface coating. The failure energy decreased from about 500 ft-lbs for the uncoated, unconditioned polycarbonate to 20 ft-lbs for the coated specimens with a 4.96 inch span. Thermally cycled specimens, also presented in Table B.11, failed at 470 ft-lbs which is only a slight reduction in the failure energy. Table B.12 presents the results of tests conducted using various one-inch diameter impactors which had different geometrical configurations and surface finishes. Although this data was limited, there appears to be about a 5% decrease in the threshold energy for specimens tested with the polished (4 Lapped Surface) impactor; however, the results in Table B.10 indicate a 5% increase in energy for the polished impactor.

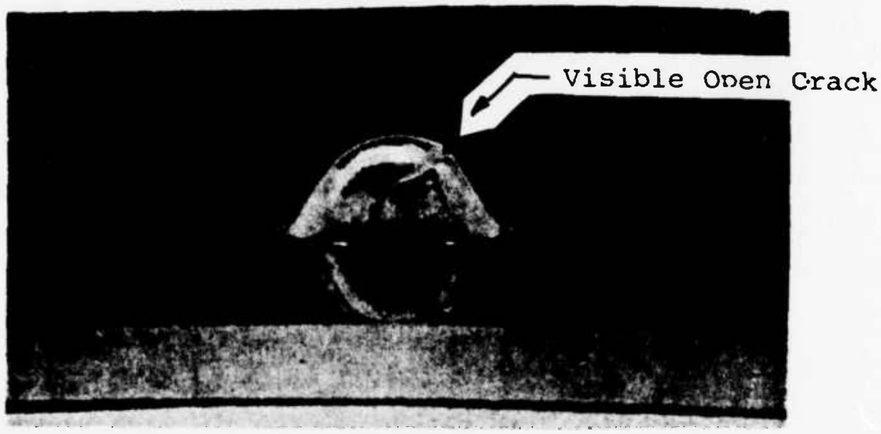
Table B.13 presents the data for tests conducted with various size impactors and plate spans on 0.31 inch thick uncoated polycarbonate. The limited amount of data appears to follow the trends presented in Figure 13 for the 0.25 inch thick specimens. However, no conclusive evaluation could be made.

The test results for the 0.5 inch thick uncoated polycarbonate are summarized in Table B.14. Table 1 presents a summary of the falling weight plate test results. Figure 17 shows the threshold of failure energy as a function of material thickness. The energy increases at an increasing rate with greater material thicknesses, which is similar to the trend seen in Figure 15 with the increasing impactor size. The air cannon test results followed the same trend, only at a higher energy level.

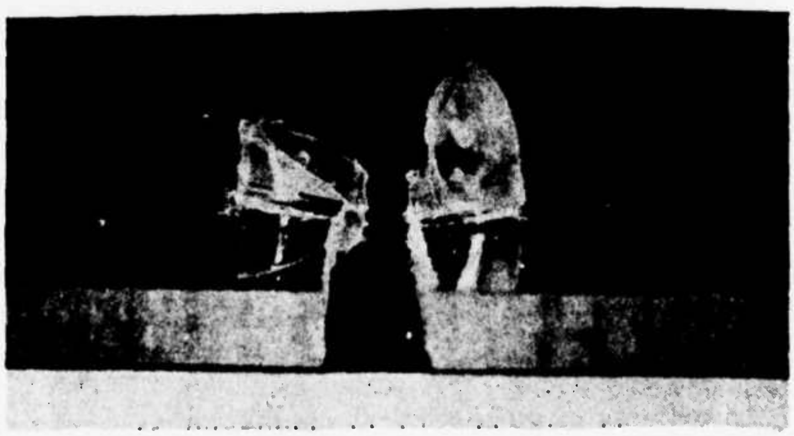
In order to correlate the results of plate tests conducted on different material thicknesses using different size impactors and plate spans, the material thickness at the point of



Typical Ductile Deformation Prior to Failure



Typical Failure Threshold



Typical Penetration Beyond the Failure Threshold
(Specimen was sawed in half to remove the impactor.)

Figure 16. 0.31" Thick Uncoated MIL-P-83310 Polycarbonate Plate Test Specimens.

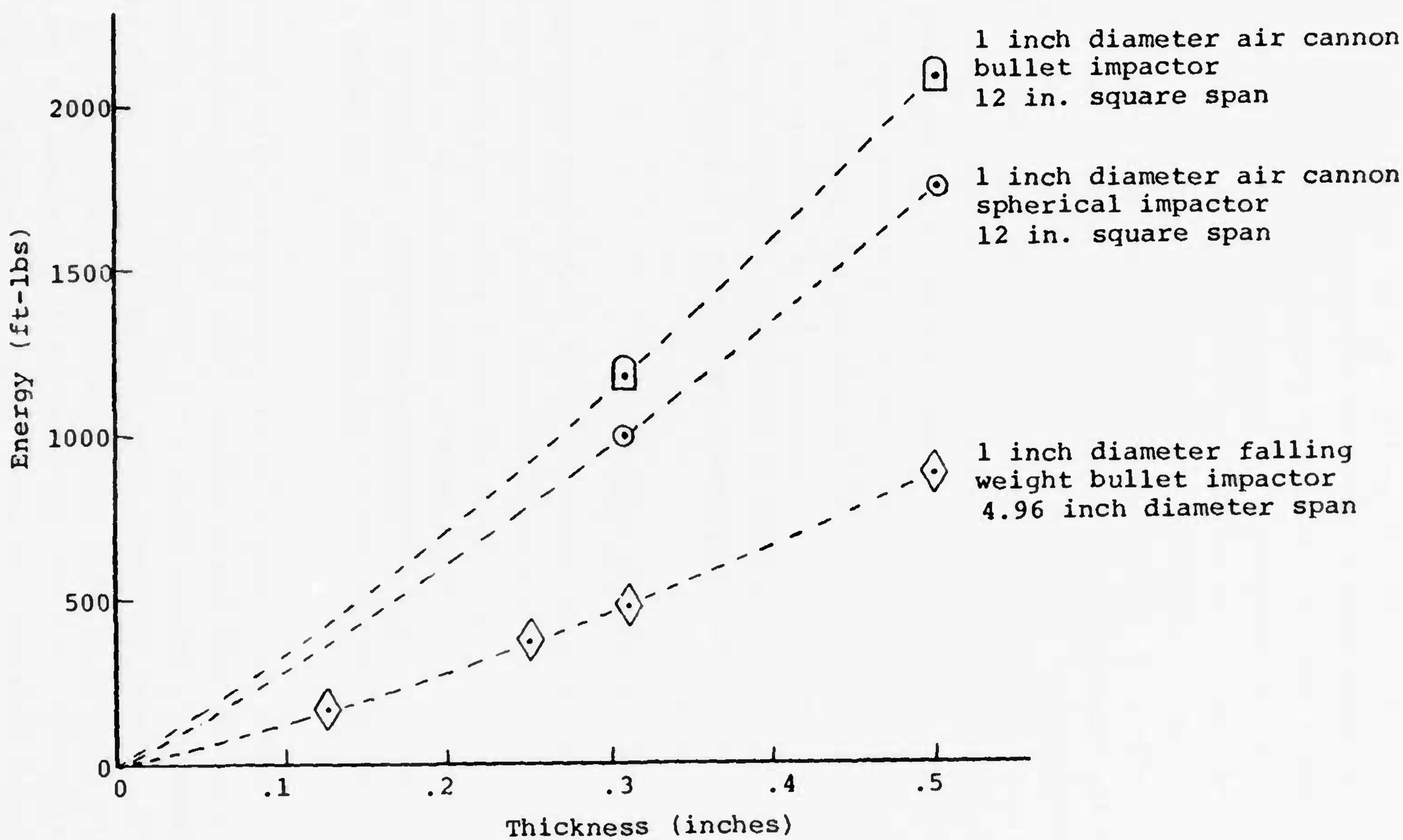


Figure 17. Threshold Energy versus Thickness.

impact was measured to determine the percent reduction in thickness. The results of measurements taken on representative plate specimens which have been tested at threshold energy are presented in Table 2. Typically unconditioned polycarbonate demonstrates 60 to 100 percent elongation in tension which is similar to the measured percent reduction in thickness for the plate specimens. The maximum percent reduction in thickness is not equivalent to (generally less than) the maximum percent elongation because of the complex strain distribution. Although this data is limited, there appears to be a greater percent reduction in thickness for tests conducted with smaller diameter impactors, and there appears to be no significant difference in the percent reduction in thickness between the air cannon and falling weight specimens despite the differences in the threshold-of-failure energy levels. By measuring the percent reduction in thickness, it is possible to compare the relative impact resistance of materials of different thicknesses and materials tested with different impactors and plate spans at different velocities.

4.3.2 Falling Weight Beam Tests

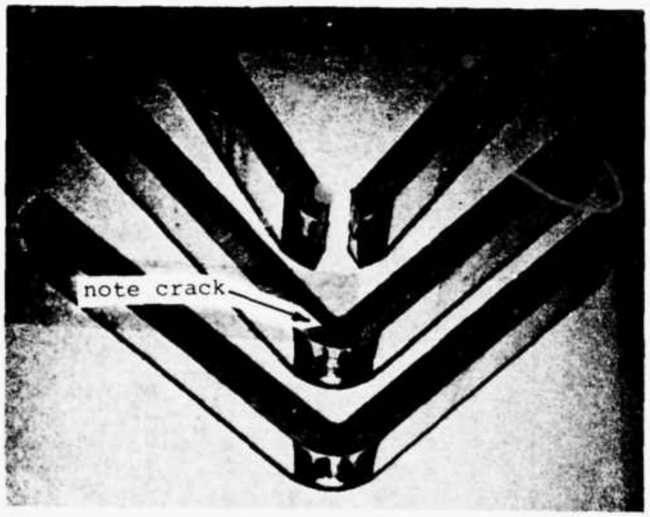
Twenty-eight falling weight beam tests were conducted on polycarbonate beam type specimens; 18 tests were conducted on 0.31 inch thick uncoated polycarbonate, 6 tests were conducted on 0.31 inch thick coated polycarbonate, and 4 tests were conducted on 0.5 inch thick uncoated polycarbonate beams. A typical failed (failure is defined as a visible open crack) beam is shown in Figure 18.

Table B.15 (Appendix B) presents the data for the 0.31 inch thick polycarbonate beams. Four uncoated polycarbonate beam specimens were tested using a 3.1 inch span (10:1 span-to-depth ratio). These specimens were deformed to the limits of the test fixture (pushed between the supports) and could not be failed (fractured). A 1.86 inch span (6:1 span-to-depth ratio) was used on the remaining fourteen beams which resulted in a threshold energy of 85 ft-lbs. Six beams were fabricated from

TABLE 2

SUMMARY OF SPECIMEN THICKNESS REDUCTION

Specimen Identification	Impactor Size (inches)	Plate Span (inches)	Thickness (inches)	Percent Reduction
<u>Thickness .125"</u>				
20-TC	1	4.0	.053	58
<u>Thickness .25"</u>				
DB-62	¼	4.0	.068	73
DB-63	¼	4.0	.068	73
DB-10	1	4.0	.100	60
DB-30	1	4.0	.095	62
DB-33	1	4.0	.106	58
DB-3	1½	4.0	.098	61
DB-39	1½	4.0	.100	60
DB-1	2	4.0	.103	59
CB-7	½	4.96	.056	78
CB-13	½	4.96	.058	77
CB-17	½	4.96	.047	81
CB-23X	1	4.96	.103	59
CB-26	1	4.96	.100	60
CB-28	1	4.96	.104	58
CB-34	1	4.96	.100	60
CB-40	1½	4.96	.100	60
CB-50	1½	4.96	.097	61
BB-23	1	8.0	.100	60
BB-35	1	8.0	.086	66
<u>Thickness .31"</u>				
DA-15	1	4.0	.125	60
DA-16	1	4.0	.123	60
DA-17	1	4.0	.136	56
DA-2R	1	4.0	.113	64
DA-12R	1	4.0	.115	64
(Air Cannon)				
AA-4	1	10	.132	57
AA-2R	1	10	.132	57
(Air Cannon)				
AG-6	1	10	.123	75
AG-9	1	10	.267	47



Typical Split Beam
Typical Failed Beam
Typical Deformed Beam Prior to Failure

Figure 18. 0.31-inch Thick Uncoated Polycarbonate Beam Test Specimens.

coated polycarbonate and tested with a 3.1 inch span; the embrittling effect of the FX-103 coating was evident in that these specimens failed at 5 ft-lbs of energy with the coated side in tension. The FX-103 coating on the surface of the polycarbonate reduced the impact strength to a level similar to acrylic.

Table B.16 presents the data for the 0.46 inch thick acrylic and the 0.5 inch thick uncoated polycarbonate beam specimens tested with a 6:1 span-to-depth ratio. The six acrylic beams shattered at 10 ft-lbs, whereas a polycarbonate beam was deflected to the limits of the supports at 170 ft-lbs of energy. These tests demonstrate the differences in toughness between the two materials.

The beam type specimens were more difficult to fabricate than plate specimens. However, they were more easily tested than plate specimens, and they produced good results when ranking the relative toughness of materials. The only real problem occurred when testing very tough and ductile materials, which are deflected to the limits of the supports without failure.

4.4 NOTCHED IZOD AND NOTCHED CHARPY TESTS

The notched Izod tests were conducted in accordance with ASTM D256-73, Method A; test results being presented in Table B.16. This test method was also very sensitive in detecting embrittlement produced by coating the nominal 0.125 inch thick polycarbonate material with FX-103, as was the falling weight test method. The Izod test method also detected a polycarbonate embrittlement as a result of the thermal cycle conditioning of the 0.125 inch thick material which was not detected by the falling weight tests.

For the nominal 0.310 inch thick polycarbonate material, the behavior was brittle at all the tested material conditions, with only a small decrease in impact strength produced by the 'C' and 'TC' conditioning. In the falling weight tests, the behavior of the 'AR' 0.31 inch thick material was ductile with large decreases in strength produced by the 'C' conditioning.

As can be seen in Table B.16, the notched Charpy test results are essentially equivalent to the notched Izod results and the same conclusions apply.

4.5 SIMPLY-SUPPORTED THREE-POINT FLEXURE TESTS

The simply-supported three-point flexure test results are presented in Appendix B in Table B.17. These tests were conducted in accordance with ASTM D790-71, Method I, with the exception that the ram velocity was adjusted to produce the fiber strain rates listed in the table. The mechanical properties documented in the table were determined from the load versus displacement test curve generated during each test. Since the elastic response of the specimens produced a nonlinear load versus displacement relationship in this test, the secant stiffness and secant elastic modulus are reported for a 2% maximum fiber strain. The maximum fiber stress was calculated for the maximum load on the load versus displacement curves and reported as the ultimate stress. The energy consumed in straining the specimen to the ultimate stress was also measured and is reported.

The mechanical property values increase with increasing strain rate; however, all failure modes were ductile (plastic hinge). Higher rates may increase sensitivity and result in material properties more representative of those relating to bird impact.

The specimens of the 'C' condition were tested with the coated side in tension. The behavior of these specimens was ductile with hairline fractures observed in the coating under the loading nose (center support). There was not a statistically significant effect produced by the 'C' conditioning in the mechanical properties at the 99% confidence level.

4.6 HIGH RATE TENSION TESTS

High rate tension tests were not conducted because of the high cost of the test fixturing required, the high cost of the specimen, and the limited funds available. Despite the higher costs of performing these tests, this is a very promising test method. In order to generate strain rates representative of those in a bird impact, a high performance electrohydraulic test machine must be used. The quantitative tensile modulus and tensile strengths would be valuable parameters for use in the design and analysis of bird impact resistant transparencies.

SECTION 5

CONCLUSIONS AND RECOMMENDATIONS

Table 3 presents a summary of the test methods considered for evaluating material embrittlement. The falling weight test method offers low cost, very good sensitivity and repeatability, and excellent adaptability to a variety of materials. The high-rate simply-supported three-point flexure test method is similar to the falling weight test with the Type "B" beam specimens. The advantage is that the results are quantitative but the cost is much higher. The notched Izod and notched Charpy tests demonstrated the greatest sensitivity of any of the evaluated test methods, possibly because of the high strain rates. The sensitivity of the air cannon and high-rate tension test was not evaluated.

The falling weight impact test method is, at this time, the recommended test method for experimentally evaluating the impact resistance of polycarbonate material. The method offers a good compromise of sensitivity, versatility, applicability, and overall cost. Based on the tests conducted under this effort, a standard test method for determining the impact resistance of monolithic polycarbonate by means of a falling weight has been generated and adopted as ASTM F736-81 (reference Appendix A).

Recommendations are outlined below.

a. Additional high velocity (strain rate) impact testing (air cannon) of polycarbonate to be evaluated at both higher and lower velocities than tested. This testing is necessary to better understand the effects of strain rate on material properties. Also, testing needs to be conducted on aged material to better evaluate the test sensitivity.

b. An investigation be conducted to utilize fracture toughness test methods as a means for evaluating the impact resistance of polycarbonate.

TABLE 3

SUMMARY OF TEST METHODS CONSIDERED FOR EVALUATING MATERIAL EMBRITTLEMENT

Test Method	Strain Rates Attainable $\left(\frac{in/in}{sec}\right)$	Repeatability of Test Results	Adaptability to Variety of Materials	Applicability Failure Mode Relevant to Those in Service	Test Sensitivity to Embrittlement	Testing Cost	Specimen Cost	Cost of Test Apparatus	Test Data
Air Cannon	10,000	Good	Excellent	Yes	--	Very High	Very Low	High	Qualitative
Falling Weight	400	Very Good	Excellent	Yes	Very Good	Very Low	Average	Low	Qualitative
Notched Izod	2,500	Very Good	Good	Yes	Excellent	Low	High	Low	Qualitative
Notched Charpy	1,200	Very Good	Good	Yes	Excellent	Low	High	Low	Qualitative
High Rate Simply Supported Three Point Flexure Test Method	900	Very Good	Excellent	Yes	Very Good	Low	Average	High	Qualitative Quantitative
High Rate Tension Test (MTS Machine)	1,600	Very Good	Excellent	Yes	--	High	High	High	Quantitative

c. A determination be made of the effects due to different lot material (processing variables) on the impact resistance of polycarbonate.

d. An investigation be conducted using high rate tension tests to determine the effects of embrittlement on the percent elongation and elastic modulus. This information is necessary to improve computer simulated failure modes.

e. Additional simply-supported three-point flexure testing at even higher strain rates be attempted in order to determine if a brittle transition occurs in unnotched samples. The higher rates may increase the sensitivity of this test and make it more representative of a bird impact.

REFERENCES

1. Michael P. Bouchard, "Effects of Surface Flaws on Impact Resistance of Uncoated Polycarbonate," UDR-TR-82-74, University of Dayton, Dayton, Ohio, June 1982.

2. Kenneth I. Clayton, John F. Milholland, and Gregory J. Stenger, "Experimental Evaluation of F-16 Polycarbonate Canopy Material," AFWAL-TR-81-4020, Wright-Patterson Air Force Base, Ohio, April 1981.

3. K. I. Clayton, P. E. Johnson, and B. S. West, "Evaluation of Impact Resistance Test Methods for Polycarbonate," UDR-TR-80-06, University of Dayton, Dayton, Ohio, January 1980.

APPENDIX A

Standard Test Method for

IMPACT RESISTANCE OF MONOLITHIC POLYCARBONATE SHEET BY MEANS OF A FALLING WEIGHT

Designation: F 736 - 81

AMERICAN SOCIETY FOR TESTING AND MATERIALS
1916 Race St., Philadelphia, Pa. 19103
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Standard Practice for IMPACT RESISTANCE OF MONOLITHIC POLYCARBONATE SHEET BY MEANS OF A FALLING WEIGHT[1]

This standard is issued under the fixed designation F 736; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope

1.1 This practice covers the determination of the energy required to initiate failure in monolithic polycarbonate sheet material under specified conditions of impact using a free falling weight.

1.2 Two specimen types are defined as follows:

1.2.1 *Type A* consists of a flat plate test specimen and employs a clamped ring support.

1.2.2 *Type B* consists of a simply supported three-point loaded beam specimen (Reference Fig. 1) and is recommended for use with material which can not be failed using the Type A specimen. For a maximum drop height of 6.096 m (20 ft) and a maximum drop weight of 22.68 kg (50 lb), virgin polycarbonate greater than 12.70 mm (½ in.) thick will probably require use of the Type B specimen.

NOTE 1—See also ASTM Methods: D 1709, D 2444 and D 3029.

2. Applicable Documents

2.1 *ASTM Standards*:

D 618 Conditioning Plastics and Electrical Insulating Materials for Testing[2]

D 790 Test for Flexural Properties of Plastics[3]

3. Summary of Practice

3.1 The test procedure to cause failure covers a range of impact energies and differs with respect to geometry and support of test specimen Type A and test specimen Type B. Guidelines are established to control drop heights, impact velocity, drop weights, impactor heads, impactor release, impactor rebound, impact location, and specimen configuration which are applicable to a falling weight impact tester designed to accommodate Type A or Type B test specimens, or both, fabricated from monolithic polycarbonate sheet material.

4. Significance and Use

4.1 This practice is applicable for qualitatively evaluating coated and uncoated monolithic polycarbonate sheet material, for monitoring process control, for screening studies, and as an aid in the prediction of hardware performance when exposed to impact service conditions.

4.2 A limitation of Type A specimen testing is that a thick sheet may not fail since the available impact energy is limited by the maximum drop height and falling weight capacity of the test apparatus. Use Specimen Type A for material less than 12.7 mm (0.50 in.) thick.

4.3 Within the range of drop heights of this system, tests employing different velocities are not expected to produce different results. However, for a given series of tests, it is recommended that the drop height be held approximately constant so that velocity of impact (strain rate) will not be a variable.

[1] This practice is under the jurisdiction of ASTM Committee F-7 on Aerospace Industry Methods and is the direct responsibility of Subcommittee F07.08 on Transparent Enclosures and Materials.

Current edition approved Aug. 28, 1981. Published October 1981.

[2] *Annual Book of ASTM Standards*, Part 25.

[3] *Annual Book of ASTM Standards*, Part 35.

4.4 As the polycarbonate specimen undergoes large plastic deformation under impact, the down (opposite impact) side is under tensile loading and most influential in initiating failure. Polycarbonate sheet coated on one side may yield significantly different test results when tested with the coated side down versus the coated side up.

4.5 Direct comparison of specimen Type A and specimen Type B test results should not be attempted. For test programs that will require the comparison of interlaboratory test results the specimen type and the approximate drop height must be specified.

4.6 Monolithic polycarbonate sheet is notch sensitive. Data obtained from other test methods, particularly notched Izod/Charpy test results, and extremely high- or low-strain rate test results, should not be compared directly to data obtained from this method. It is noted that Type A specimens, free of flaws, have not experienced the characteristic ductile-to-brittle transition between thin, less than 3.18 mm (⅛ in.), and thick, greater than 7.94 mm (5⁄16 in.), sheet as reflected by other test methods.

5. Descriptions of Terms

5.1 *failure (of test specimen)*—failure is signified by the presence of any crack or split in the impact-deformed area that was created by the impact of the falling weight and that can be seen by the naked eye.

6. Apparatus

6.1 *Impact Tester*—The apparatus shall be constructed essentially as shown in Fig. 2. Although not specified, materials called out have been found to be satisfactory.

6.1.1 *Drop Height*—A lifting carrier shall be provided to raise or lower the falling weight impactor that will be adjustable within the range of 0.305 m (1 ft) to maximum drop height and measurable to the nearest 25.40 mm (1 in.).

6.1.2 *Drop Weight*—The falling weights shall be detachable, interchangeable, and variable in small known increments from a total of 0.45 kg (1 lb) to a maximum drop weight of 50 kg (110 lb).

6.1.3 *Impactor*—The loading nose to be used with Type A specimens is shown in Fig. 3, with Type B specimens as shown in Fig. 4. The impactor surface shall be free of nicks or other surface irregularities. The impactor geometry for Type B specimens corresponds to Method D 790.

6.1.4 *Impact Location*—The center of mass of the falling weight shall be guided by a two cable system or other suitable means to repeatedly strike within 2.54 mm (0.10 in.) of the center of the specimen support fixture as measured in the plane of the specimen, in order to assure uniform, reproducible drops. Friction retarding the falling weight should be minimal so that the impact velocity approaches

$$\sqrt{2gh}$$

where:

g = acceleration of gravity, and
h = drop height.

6.1.5 *Supports*—Clamp and support rings as shown in Fig. 5 and Table 1 will be used to accommodate Type A plate specimens. Adjustable D 790–Method 1 supports will be used to accommodate the Type B simply supported beam specimens of 6 + 1 span-to-depth ratio. Specimens shall be supported so that the surface to be impacted is horizontal and at an angle of 90 (± 1) ° ($\pi/2$ radians) with respect to the falling weight guides.

6.1.6 *Release*—An electromagnetic or mechanical releasing mechanism, capable of supporting the maximum falling weight, will be provided to assure uniform and reproducible drops.

6.1.7 *Rebound Catcher*—Means must be provided to catch the weight if it rebounds to prevent restriking the specimen and causing further damage.

6.1.8 *Energy Absorber*—An energy absorbent material must be provided beneath the specimen to prevent damage to the fixture when the impactor penetrates the specimen.

7. Precautions

7.1 To reduce a hazard to the test operator or witness, or both, a protective enclosure shall be placed around the test specimen impact area to contain any flying particles which may be generated during the test. No further adjustments to the specimen shall be made after positioning the falling weight at the selected drop height.

8. Test Specimens

8.1 All specimens must be initially without flaws unless the flaws constitute variables under study. Type B specimens must be free of machining stresses. Edge stresses associated with standard shop practice do not affect the test results for Type A specimens. If no combination of falling weight/drop height is available that will give satisfactory results using Type A specimens because of high impact resistance, the use of Type B specimens is recommended to produce failure at a lower energy level.

8.1.1 *Type A*—Flat plates shall be round or square and have the physical dimensions specified in Table 2. These dimensions provide adequate edge distance for clamping on the plate support rings.

8.1.2 *Type B*—For beam specimens greater than 12.7 mm (0.50 in.) thick the support span shall be six times the thickness of the beam, the specimen width shall be two times the thickness, not to exceed 50.80 mm (2.00 in.), and the overhang on each end shall be four times the thickness to prevent the specimen from slipping through the supports.

NOTE 2—With care, Type A plate specimens may be handsawed without inducing failure from edge effects. Type B beam specimens must have deburred finish-machined edges that are free of stress risers.

9. Conditioning

9.1 Unless otherwise specified, condition the test specimens in accordance with Procedure A of Method D 618.

10. Procedure

10.1 Measure and record the thickness and geometry of each specimen.

10.2 Choose a specimen at random from the sample.

10.3 Lightly clamp (finger tight) the specimen.

10.4 Adjust the falling weight to that weight which is expected to cause failure.

10.5 Position the falling weight at the proper height to provide the predicted failure energy at impact.

10.6 Release the weight to strike the center of the specimen. If rebound occurs, prevent the impactor from restriking the specimen.

10.7 Examine the specimen to determine if it failed. Test each specimen only once. If over (full penetration) or under the threshold of failure, remove or add an increment of weight as derived from results observed from the specimen tested immediately prior and repeat the test procedure.

10.8 Use a sufficient number of specimens to determine the threshold of failure, using trial and error test runs. Test six replicates at failure energy so that at least two, and not more than four, of the samples tested fail at the given energy level.

10.9 Exercise care to avoid accidental exposure of polycarbonate test samples to toluene, MEK vapors, and other harmful solvents. Degradation can occur with no visual evidence of damage.

11. Calculations

11.1 The energy required to produce failure, expressed in foot-pounds, is obtained by multiplying the falling weight by the drop height.

12. Report

12.1 The report shall include the following:

12.1.1 Complete identification of the material,

12.1.2 Type of specimen (either A or B),

12.1.3 Specimen fabrication procedure,

12.1.4 Thickness,

12.1.5 Number of test specimens employed to determine threshold of failure,

12.1.6 Test conditions and material history,

12.1.7 Failure energy,

12.1.8 Drop height,

12.1.9 Drop weight,

12.1.10 Failure mode (ductile deformation, penetration, or brittle fracture),

12.1.11 Replicate data,

12.1.12 Deviation(s) from test procedure, and

12.1.13 Date of test.

13. Precision and Accuracy

13.1 Limited data from one laboratory indicates repeatability to approximately ± 5 % for either specimen Type A or Type B for material exhibiting ductile behavior.

TABLE 1 Plate Support Ring Geometry

NOTE—Reference Fig. 5 for definition of "A" and "C."

Ring Size	"A"	"C"	Span
	mm (in.)	mm (in.)	mm (in.)
1	88.9 (3.50)	127.0 (5.00)	101.6 (4.00)
2	114.3 (4.50)	157.5 (6.20)	127.0 (5.00)
3	190.5 (7.50)	254.0 (10.00)	203.2 (8.00)
4	292.1 (11.50)	381.0 (15.00)	304.8 (12.00)

TABLE 2 Type A Specimen Geometry[A]

Specimen Thickness	Span[B] ("A" + 2R)	Diameter or Width	Span/Thickness
mm (in.)	mm (in.)	mm (in.)	
3.175 (0.125)– 7.94 (0.3125)	101.6 (4.00)	127.0 (5.00)	32–12.8
7.95 (0.3130)–12.80 (0.5040)	127.0 (5.00)	157.5 (6.20)	16–9.9
12.81 (0.5045)–19.30 (0.760)	203.2 (8.00)	254.0 (10.00)	15.9–10.5
19.31 (0.765)–32.00 (1.26)	304.8 (12.00)	381.0 (15.00)	15.8–9.5

[A] Specified specimen thicknesses are nominal thicknesses. Tolerances on actual material thickness could cause specimens from a given group to fall in more than one thickness range. This should not be permitted. All specimens having the same nominal thickness should be tested at the same span.

[B] Reference Fig. 5.

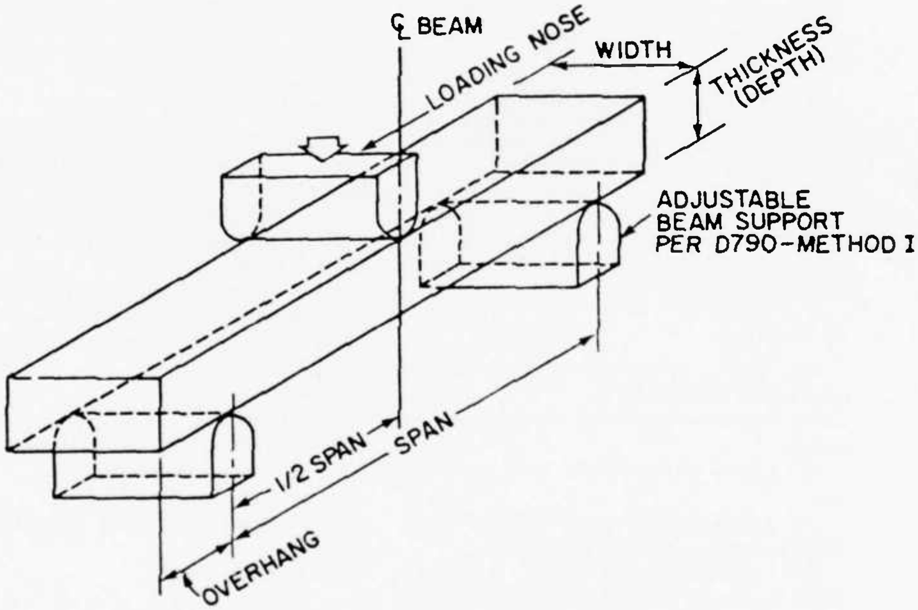


FIG. 1 Type B Specimen Geometry and Loading

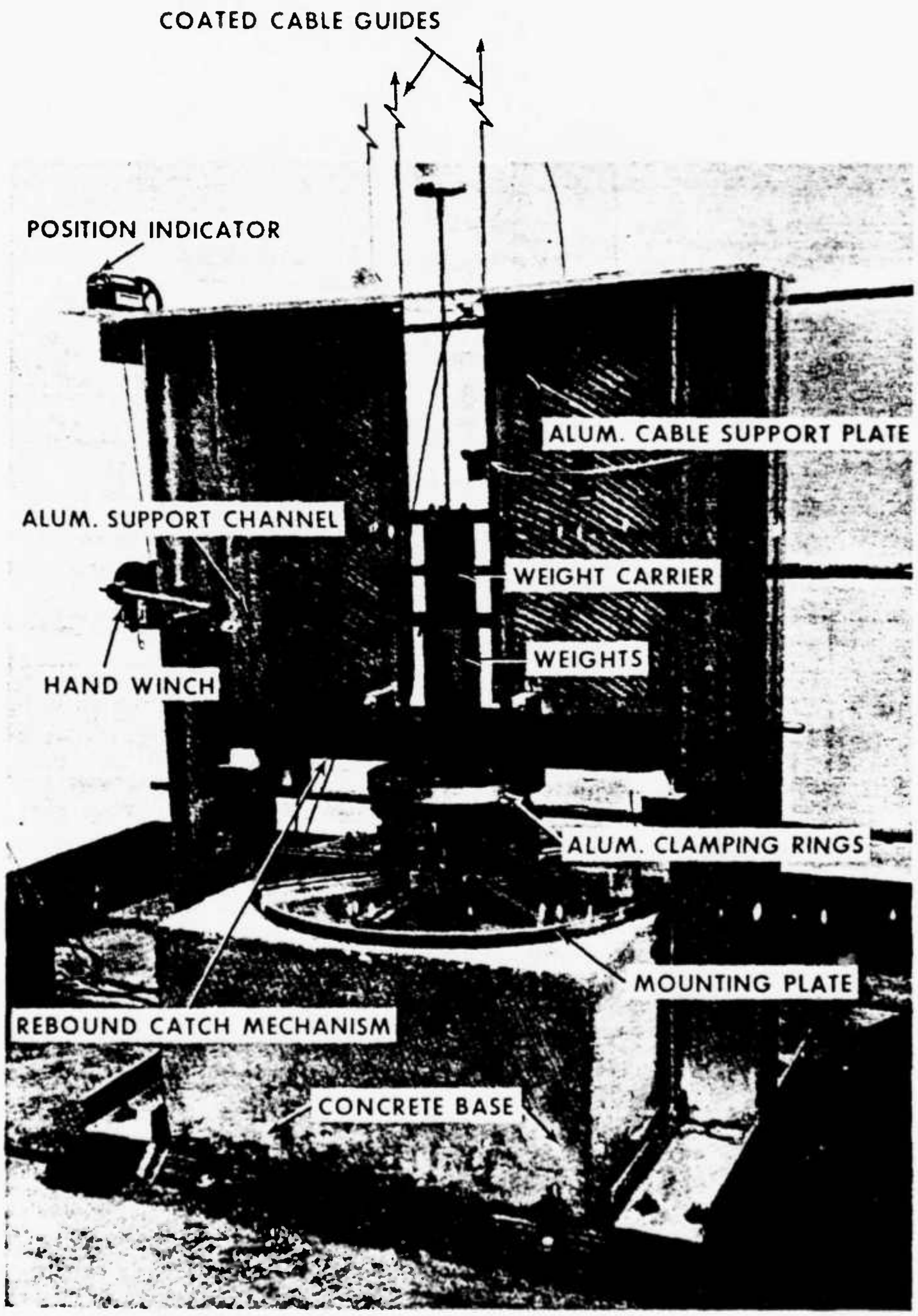
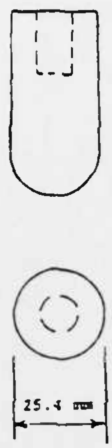
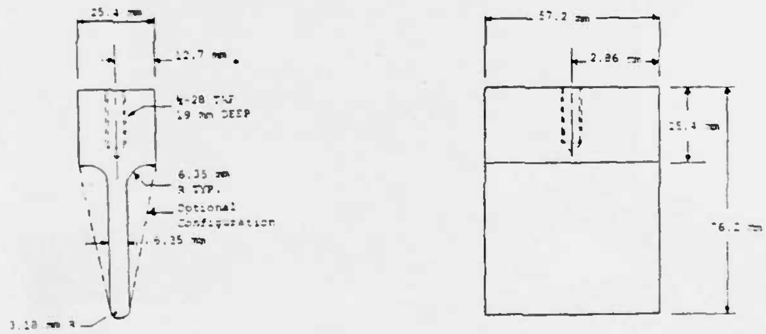


FIG. 2 Falling Weight Impact Tester



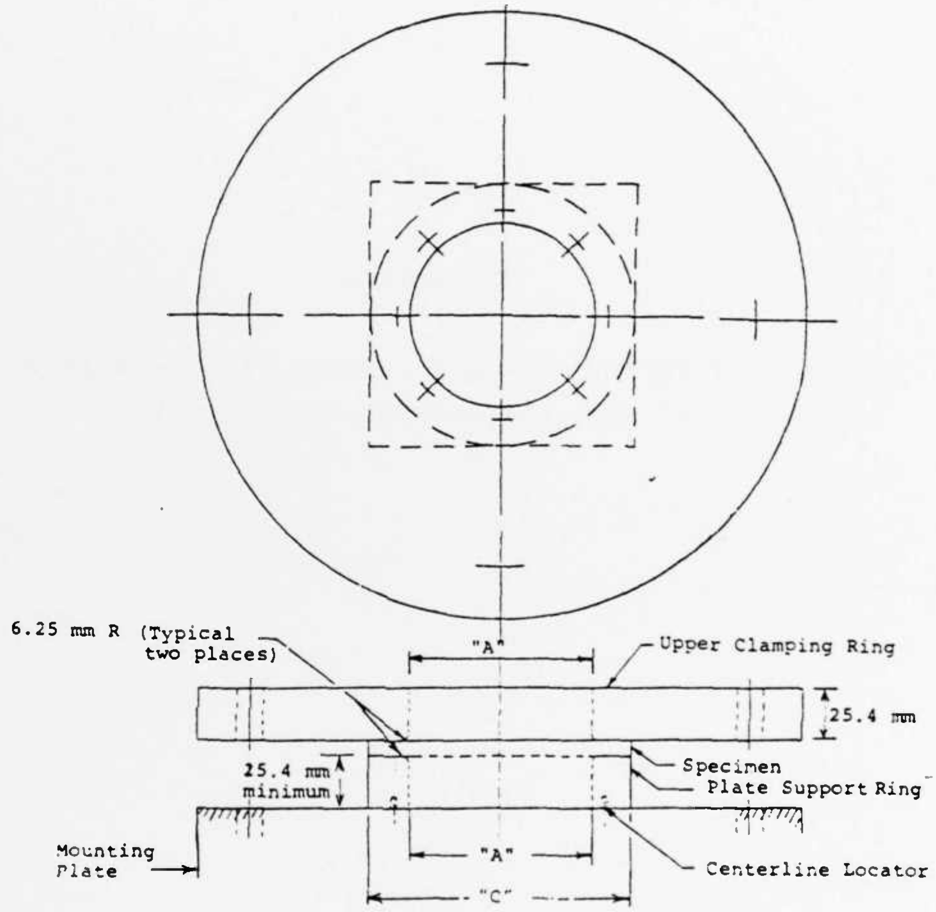
NOTE—All loading surfaces to have surface roughness of 1.5-3.0 μm (64-128 μin.).

FIG. 3 Impactor Loading Nose—Type A Plate Specimen (Stainless Steel)



NOTE—All loading surfaces to have surface roughness of 1.5-3.0 μm (64-128 μin.).

FIG. 4 Impactor Loading Nose—Type B Beam Specimen (Stainless Steel)



NOTE 1—Reference Table 1 for dimensions "A" and "C".
NOTE 2—All loading surfaces to have surface roughness of 1.5–3.0 μm (64–128 μin.).

FIG. 5 Clamping and Support Rings—Type A Plate Specimen

APPENDIX B

ACTUAL TEST RESULTS FOR AIR CANNON, FALLING WEIGHT, NOTCHED IZOD, AND NOTCHED CHARPY TESTS

TABLE B.1
AIR CANNON TEST

Uncoated Polycarbonate .31 Inch Thick Mil. Spec. G.E. Lexan* 10 x 10 Plate Span

Specimen Number	Impactor Type	Impactor Mass (gm)	Velocity ft./sec.	Energy ft.-lbs.	Failure Type
AA-1	Sphere	66.7	473	510	D
AA-3	1 inch.		597	810	D
AA-6	Dia.		627	900	D
AA-7			637	930	D
AA-4			651	970	F
AA-8			656	980	D
AA-5			666	1,010	P
AA-2			709	1,150	P
AA-2R	(Rohm & Haas) Tuffak	66.7	644	950	F
AA-1R		66.7	808	1,490	P
AA-16	Bullet	287	284	793	D
AA-17	1 inch		345	1,170	D
AA-21	Dia.	286.9	345	1,170	P
AA-20	Hemi-nose		355	1,240	P
AA-19			361	1,280	P
AA-15		287.2	375	1,380	P

* except as noted
D-ductile deformation
F-threshold of failure - visible open crack
P-penetration

TABLE B.2
AIR CANNON TEST

Uncoated Polycarbonate .5 inch Thick Commercial G.E. Lexan 10 x 10 Plate Span

Specimen Number	Impactor Type	Impactor Mass (gm)	Velocity ft./sec.	Energy ft.-lbs.	Failure Type
AC-2	Sphere	66.7	826	1,560	D
AC-4	1 inch		Est. 850	1,650	D
AC-5	Dia.		867	1,720	D
AC-3			870	1,730	P
AC-6			873	1,740	D
AC-7			873	1,740	D
AC-8			886	1,790	P
AC-1			898	1,840	P
AC-12	Bullet	287	421	1,740	D
AC-10	1 inch		447	1,960	D
AC-13	Dia.		448	1,970	D
AC-15	Hemi-nose		452	2,010	P
AC-9			461	2,090	D
AC-14			467	2,140	D
AC-11			492	2,380	P

D-ductile deformation
F-threshold of failure - visible open crack
P-penetration

TABLE B.3

FALLING WEIGHT TEST RESULTS
PLATE SPECIMENS - CLAMPED EDGE

Uncoated MIL-P-83310 Polycarbonate, 0.125" Thickness

Plate Span in.	Specimen No.	Drop Height, ft.	Falling Weight, lbs.	Energy ft-lbs.	Failure (1)
1" Dia. Ball Nose Impactor					
4.96 dia.	2T	10.00	16.50	165	D
	3T	11.38	14.50	165	D
	4T	17.15	9.62	165	D
	7T	7.23	22.82	165	P
	6T	7.89	22.82	180	P
	27R	5.18	34.77	180	D
	28R	5.32	34.77	185	F
	29R	5.46	34.77	190	P
	30R	5.46	34.77	190	F
	5T	10.00	22.82	228	P
	1T	20.00	16.50	330	P
8.00 dia.	62	7.23	22.82	165	D
	63	7.23	22.82	165	D
	64	7.23	22.82	165	D
	65	7.50	22.82	171	D
	66	7.89	22.82	180	D
	66C	18.03	10.54	190	D
	66B	8.33	22.82	190	D
	66A	8.76	22.82	200	P
1" Dia. Heat Treated Bullet Impactor					
8.00 dia.	2	12.58	15.5	195	D
	3	12.90	15.5	200	D
	1	13.22	15.5	205	D

(1) D = Ductile Deformation
F = Failure Threshold - Visible Crack
P = Penetration

TABLE B.4

FALLING WEIGHT TEST RESULTS
PLATE SPECIMENS - CLAMPED EDGE

Coated MIL-P-83310 As-Received Condition Polycarbonate
0.125" Thickness

Plate Span, in.	Speci-men No.	Drop Height ft.	Falling Weight lbs.	Energy ft-lbs.	Failure (1)	Comments
1" Dia. Ball Nose Impactor						
4.96 dia.	44T	5.00	3.63	18.15	D	Coated side up
	45T	10.00	3.63	36.30	D	" " "
	46T	14.00	3.63	50.82	D	" " "
	47T	10.00	13.65	136.50	S	" " "
	42T	1.00	3.63	3.63	F	Coated side down
	43T	1.00	3.63	3.63	F	" " "
	41T	1.65	3.63	5.99	S	" " "
	40T	2.50	3.63	9.08	S	" " "

Uncoated MIL-P-83310 Polycarbonate, 0.125" Thickness
Specimens thermal cycled at 257°F as noted

Plate Span, in.	Speci-men No.	Drop Height ft.	Falling Weight lbs.	Energy ft-lbs.	Failure (1)	Comments
1" Dia. Ball Nose Impactor						
4.96 dia.	5TC	4.19	33.38	140	D	
	6TC	4.19	33.38	140	D	
	7TC	4.19	33.38	140	D	
	8TC	4.19	33.38	140	D	
	4TC	4.94	33.38	165	P	
1" Dia. Heat Treated Bullet Impactor						
4.96 dia.	22TC	9.03	15.5	140	D	16 hrs @ 257°F
	20TC	9.68	15.5	150	D	" "
	17TC	10.00	15.5	155	D	" "
	18TC	10.00	15.5	155	D	" "
	19TC	10.00	15.5	155	P	2 hrs @ 257°F
	21TC	10.32	15.5	160	P	" "

(1) D = Ductile Deformation
F = Failure Threshold - Visible Crack
S = Shatter
P = Penetration

TABLE B.5

FALLING WEIGHT TEST, UNCOATED COMMERCIAL GRADE POLYCARBONATE*
.250 INCHES THICK, SPAN = 4 INCHES

Specimen Number	Drop Height ft.	Falling Weight lbs.	Energy ft.-lbs.	Impactor Type	Failure Type
DB-60	6.15	5.7	35	1/4 inch Diameter Bullet	D
DB-61	7.03	5.7	40		D
DB-62	7.91	5.7	45		F
DB-63	7.91	5.7	45		F
DB-59	8.79	5.7	50		P
DB-58	13.18	5.7	75		P

D-ductile deformation
F-threshold of failure
P-penetration

* Lexan

TABLE B.5 (continued)

Specimen Number	Drop Height ft.	Falling Weight lbs.	Energy ft.-lbs.	Impactor Type	Failure Type
DB-13	9.6	12.7	120	½" Bullet	D
DB-14	9.6		120		D
DB-12	9.6		120		F
DB-15	10.0		125		D
DB-18	10.0		125		D
DB-22	10.0		125		D
DB-19	10.5		135		D
DB-16	10.5		135		F
DB-20	10.5		135		F
DB-17	10.5		135		P
DB-21	10.5		135		P
DB-24	11.1		140		P
DB-25	11.1		140		P
DB-11	12.0		150		P
DB-7	9.7	33.1	320	1" Bullet	D
DB-31	10.4	33.0	345		D
DB-32	10.4	33.0	345		D
DB-33	10.4	33.0	345		F
DB-8	10.5	33.1	350		D
DB-9	10.7	33.1	355		D
DB-27	10.9	33.0	360		F
DB-26	10.9	33.0	360		D
DB-10	10.9	33.1	361		F
DB-28	11.1	33.0	365		D
DB-30	11.1	33.0	365		F
DB-29	11.2	33.0	370		P
DB-34	11.4	33.0	375		D
DB-35	11.6	33.0	385		F
DB-36	11.6	33.0	385		F
DB-46	15.7	49.0	770	1½" Bullet	D
DB-47	15.7	49.0	770		D
DB-48	15.9	49.0	780		F
DB-3	16.7	48.0	800		D
DB-38	16.5	49.0	810		D
DB-37	16.5	49.0	810		F
DB-45	16.5	49.0	810		P
DB-40	16.8	49.0	825		D
DB-39	16.8	49.0	825		F
DB-44	16.8	49.0	825		P
DB-43	16.9	49.0	830		D
DB-42	17.1	49.0	840		P
DB-41	17.4	49.0	850		P
DB-49	17.6	49.0	860		D
DB-50	18.0	49.0	880		P
DB-51	18.0	49.0	880		P
DB-4	18.8	48.0	900		P
DB-2	20.0	48.0	960		P
DB-1	20.00	49.0	980	2" Ball Nose	F

D-ductile deformation
F-threshold of failure
P-penetration

* Lexan

TABLE B.6

FALLING WEIGHT TEST, UNCOATED COMMERCIAL GRADE POLYCARBONATE *
.250 INCHES THICK, SPAN = 4.96 INCHES

Specimen Number	Drop Height ft.	Falling Weight lbs.	Energy ft.-lbs.	Impactor Type	Failure Type
CB-4	3.6	29.7	105	½" Bullet	D
CB-5	3.8	29.7	115		D
CB-3	4.0	29.7	120		P
CB-11	4.1	29.0	120		D
CB-22	14.0	9.0	125		D
CB-21	14.0	9.0	125		D
CB-9	14.0	9.0	125		D
CB-18	4.4	29.0	130		D
CB-12	4.4	29.0	130		D
CB-13	4.6	29.0	135		F
CB-17	4.6	29.0	135		F
CB-23	14.8	9.0	135		F
CB-7	14.8	9.0	135		F
CB-6	14.8	9.0	135		P
CB-8	14.8	9.0	135		P
CB-19	14.8	9.0	135		P
CB-14	4.8	29.1	140		P
CB-15	4.8	29.1	140		P
CB-16	4.8	29.1	140		P
CB-1	16.3	9.0	145		P
CB-2	16.3	9.0	145	↓	P
CB-30	10.6	33.0	350	1" Bullet	D
CB-31	10.6		350		D
CB-29	10.8		355		P
CB-25	11.1		365		D
CB-27	11.4		375		D
CB-26	11.4		375		F
CB-24	11.4		375		P
CB-28	11.4		375		F
CB-19	11.7		385		D
CB-22	11.7		385		P
CB-23	11.7		385		P
CB-21	12.0		395		P
CB-33	12.2		405		D
CB-32	12.2		405		P
CB-34	12.2		405		F
CB-36	12.7		420		F
CB-35	12.7	↓	420	↓	P
CB-48	15.0	49.0	735	1½" Bullet	D
CB-52	15.4		755		D
CB-49	15.5		760		D
CB-47	15.6		765		P
CB-51	15.7		770		P
CB-53	16.3		800		D
CB-46	16.5		810		P
CB-39	17.1		840		D
CB-41	17.3		850		D
CB-40	17.3		850		F
CB-45	17.3		850		P
CB-50	17.4		855		P
CB-44	17.4		855		P
CB-42	17.6		860		F
CB-43	17.6		860		P
CB-38	17.7		865		P
CB-37	18.2	↓	890	↓	P

D-ductile deformation
F-threshold of failure
P-penetration

* Lexan

TABLE B.7

FALLING WEIGHT TEST, UNCOATED COMMERCIAL GRADE POLYCARBONATE *
.250 INCHES THICK, SPAN = 8.0 INCHES

Specimen Number	Drop Height ft.	Falling Weight lbs.	Energy ft.-lbs.	Impactor Type	Failure Type
BB-1	12.6	8.75	110	½" Bullet	D
BB-2	14.3		125		D
BB-8	15.4		135		D
BB-9	16.0		140		D
BB-10	16.6		145		D
BB-3	17.1		150		D
BB-11	17.1		150		D
BB-6	17.1		150		P
BB-7	17.1		150		P
BB-12	18.3		160		F
BB-13	18.3		160		F
BB-14	18.3		160		F
BB-5	18.3		160		P
BB-15	19.2		168		P
BB-16	19.2		168		P
BB-17	19.2		168		P
BB-18	19.2		168		P
BB-4	20.0		175		P
BB-34	14.6	26.0	380	1" Bullet	D
BB-36	14.6		380		D
BB-35	14.6		380		F
BB-19	15.0		390		D
BB-24	15.4		400		D
BB-25	15.4		400		D
BB-28	15.4		400		D
BB-29	15.4		400		D
BB-23	15.4		400		F
BB-30	15.4		400		P
BB-27	15.8		410		P
BB-31	16.2		420		P
BB-32	16.2		420		P
BB-33	16.2		420		P
BB-20	16.4		425		D
BB-22	16.4		425		P
BB-26	16.4		425		P
BB-21	17.3		450		P
BB-38	16.3	49.0	800	1½" Bullet	D
BB-39	16.6		815		D
BB-40	16.8		825		D
BB-37	16.8		825		P
BB-49	17.0		830		D
BB-54	17.0		830		D
BB-50	17.0		830		P
BB-41	17.4		850		D
BB-45	17.4		850		D
BB-46	17.6		860		D
BB-42	17.9		875		D
BB-48	17.9		875		D
BB-53	17.9		875		D
BB-44	17.9		875		P
BB-47	17.9		875		P
BB-43	18.4		900		P
BB-51	18.8		920		P
BB-52	18.8		920		P

D-ductile deformation
F-threshold of failure
P-penetration

*Lexan

TABLE B.8

FALLING WEIGHT TEST RESULTS, PLATE SPECIMENS - CLAMPED EDGE

Uncoated MIL-P-83310 Polycarbonate, 0.310" Thickness

Plate Span in.	Specimen No.	Drop Height, ft.	Falling Weight, lbs.	Energy ft-lbs.	Failure (1)
1" Dia. Ball Nose Impactor					
4.00 dia.	30P	13.32	33.03	440	D
	31P	13.32	33.03	440	D
	32P	13.32	33.03	440	D
	33P	13.32	33.03	440	D
	34P	13.32	33.03	440	D
	10R	13.28	34.65	460	F
	11R	13.28	34.65	460	F
	12R	13.28	34.65	460	D
	13R	13.28	34.65	460	D
	14R	13.28	34.65	460	D
	22R	13.80	34.65	478	F
	24R	9.86	48.50	478	P
	25R	18.65	25.63	478	P
	26R	13.80	34.65	478	D
	15R	13.94	34.65	483	F
	23R	10.00	48.50	485	P
	21R	14.28	34.65	495	P
	35P	14.88	33.59	500	D
	36P	14.88	33.59	500	F
	37P	14.88	33.59	500	P
	17R	14.60	34.65	506	D
	19R	15.27	34.65	529	P
	20R	15.27	34.65	529	P
	18R	15.93	34.65	522	P
4.96 dia.	10T	10.00	23.98	240	D
	11T	12.32	22.73	280	D
	12T	9.59	33.38	320	D
	13T	10.78	33.38	360	D
	14T	11.98	33.38	400	D
	15T	13.48	33.38	450	D
	40P	14.15	33.57	475	D
	41P	14.15	33.57	475	D
	42P	14.15	33.57	475	D
	43P	14.15	33.57	475	D
	44P	14.15	33.57	475	F
	38P	14.88	33.59	500	P
	39P	14.88	33.59	500	P
	9	14.98	33.58	500	F
	9A	14.98	33.38	500	F
	16T	14.98	33.38	500	D
	45P	15.64	33.57	525	F
	46P	15.64	33.57	525	P
	47P	15.64	33.57	525	P
	48P	15.64	33.57	525	P
	49P	15.64	33.57	525	P
	17T	11.91	48.27	575	P
8.00 dia.	1	17.23	33.38	575	D
	2	17.23	33.38	575	D
	3	17.23	33.38	575	F

(1) D = Ductile Deformation
F = Failure Threshold - Visible Crack
P = Penetration

TABLE B.9

FALLING WEIGHT TEST, UNCOATED MIL-P-83310 POLYCARBONATE

.310 inch Thick, Span = 4.0 inches

Specimen Number	Drop Height ft.	Falling Weight lbs.	Energy ft.-lbs.	Impactor Type	Failure Type
G. E. Lexan					
DA-7	14.9	28.5	425	1" Bullet	D
DA-8	15.8		450		D
DA-9	15.8		450		D
DA-10	15.8		450		D
DA-6	15.8		450		P
DA-11	16.6		475		D
DA-13	16.6		475		F
DA-12	16.6		475		P
DA-4	16.6		475		P
DA-5	16.6		475		P
DA-1	17.5		500		P
DA-2	17.5		500		P
DA-3	17.5		500		P
DA-17	16.6		475	1" Polished Bullet	F
DA-14	17.5		500		D
DA-15	17.5		500		F
DA-16	17.5		500		F
DA-18	18.4		525		D
Rohm & Haas Tuffak					
DA-16R	14.9	28.5	425	1" Bullet	D
DA-18R	14.9		425		D
DA-17R	14.9		425		F
DA-4R	15.8		450		D
DA-13R	15.8		450		D
DA-12R	15.8		450		F
DA-2R	16.6		475		F
DA-3R	16.6		475		P
DA-14R	16.6		475		P
DA-15R	16.6		475		P
DA-1R	17.5		500		P
DA-10R	17.5		500		P
DA-11R	17.5		500		P
DA-5R	15.8		450	1" Polished Bullet	F
DA-6R	16.6		475		D
DA-7R	17.5		500		D
DA-8R	18.4		525		F
DA-9R	18.4		525		P

D-ductile deformation
F-threshold of failure
P-penetration

TABLE B.10

FALLING WEIGHT TEST RESULTS
PLATE SPECIMENS - CLAMPED EDGE

Coated MIL-P-83310 Polycarbonate, .31 inches Thick

Plate Span, in.	Speci-men No.	Drop Height ft.	Falling Weight lbs.	Energy ft-lbs.	Failure (1)	Comments
1" Dia. Ball Nose Impactor						
4.96 dia.	34T	3.00	6.54	19.62	F	Coated side down
	35T	3.00	6.54	19.62	F	" "
	36T	3.00	6.54	19.62	D	Coated side up
	33T	4.00	6.54	26.16	F	Coated side down
	32T	6.00	6.54	39.24	S	" "
	31T	2.50	33.38	83.45	S	" "
	30T	7.50	33.38	250.35	S	" "

Uncoated MIL-P-83310 Polycarbonate, .31 inches Thick
Specimens thermal cycled 2 hrs. at 257°F

Plate Span, in.	Speci-men No.	Drop Height ft.	Falling Weight lbs.	Energy ft-lbs.	Failure (1)	Comments
4.96 dia.	1TC	6.00	6.54	39.24	D	1" Ball Nose
	3TC	11.98	33.38	400	D	" "
	2TC	14.98	33.38	500	P	" "
	9TC	14.00	33.25	465	F	1" Bullet
	13TC	14.00	33.25	465	F	" "
	10TC	14.28	33.25	475	F	" "
	11TC	14.28	33.25	475	P	" "
	12TC	14.28	33.25	475	P	" "

(1) D = Ductile Deformation
F = Failure Threshold - Visible Crack
S = Shatter
P = Penetration

TABLE B.11

FALLING WEIGHT TEST, EFFECT OF IMPACTOR FINISH

Uncoated MIL-P-83310 Polycarbonate, .31 Inches Thick
Span = 4.96 inches, 1" Dia. Impactors

Specimen Number	Drop Height ft.	Falling Weight lbs.	Energy ft-lbs.	Failure Type (1)
Impactor: Stainless Steel Bullet Configuration Surface Finish - 64 microinches				
CA12	14.81	33.75	500	D
CA13	14.81	33.75	500	D
CA14	14.81	33.75	500	F
CA1	15.04	33.25	500	F
14TC	15.04	33.25	500	P
Impactor: Alloy Steel (Heat Treated) Bullet Configuration Surface Finish - Equivalent to a "4 Lapped" Surface				
CA15	14.07	33.75	475	D
CA16	14.07	33.75	475	F
CA17	14.07	33.75	475	P
CA9	14.81	33.75	500	P
CA10	14.81	33.75	500	P
CA11	14.81	33.75	500	P
Impactor: Chrome Steel Ball Nose				
38P	14.88	33.59	500	P
39P	14.88	33.59	500	P
9	14.98	33.38	500	F
9A	14.98	33.38	500	F
16T	14.98	33.38	500	D
15TC	15.04	33.25	500	F
CA3	15.04	33.25	500	P
Impactor: Hardened Steel Bullet				
16TC	15.04	33.25	500	F
CA2	15.04	33.25	500	P

(1) D = Ductile Deformation
F = Failure Threshold - Visible Crack
P = Penetration

TABLE B.12

FALLING WEIGHT TEST, EFFECT OF PLATE SPAN

Uncoated MIL-P-83310 Polycarbonate, .31 inch Thick

Specimen Number	Drop Height ft.	Falling Weight lbs.	Energy ft-lbs.	Impactor Type	Failure Type (1)
Span = 4.0"					
DA-2	14.17	12.0	170	½" Bullet	D
DA-4	14.33		172		D
DA-5	14.58		175		D
DA-6	14.58		175		D
DA-3	14.58		175		P
DA-8	17.7	48.0	850	1½" Bullet	D
DA-9	20.0	48.0	960	1½" Bullet	D
DA-1	19.0	49.0	931	2" Ball Nose	D
Span = 4.96"					
CA-5	14.58	12.0	175	½" Bullet	D
CA-7	15.00		180		P
CA-6	15.42		185		P
CA-4	15.83		190		P
Span = 8.00"					
BA-1	10.00	15.50	155	½ Ball Nose	D
BA-4	12.90	15.50	200		D
BA-7	13.11	15.25	200		P
BA-6	13.77	15.25	210		P
BA-3	14.19	15.50	220		P
BA-2	16.13	15.50	250		P
9	17.29	33.25	575	1" Bullet	P
5	18.80		625		P
4	18.80		625		P
BA-5	16.33	49	800	2" Ball Nose	D

(1) D = Ductile Deformation
F = Failure Threshold - Visible Crack
P = Penetration

TABLE B.13

FALLING WEIGHT TEST
Uncoated Commercial Grade Polycarbonate
.5 inch Thick, Span = 4.96 inches

Specimen Number	Drop Height ft.	Falling Weight lbs.	Energy ft.-lbs.	Impactor Type	Failure Type
CC-16	16.9	48	810	1" Bullet	D
CC-17	16.9		810		D
CC-18	16.9		810		F
CC-1	17.3		830		D
CC-3	17.7		850		D
CC-15	17.7		850		D
CC-2	17.7		850		F
CC-14	17.7		850		F
CC-4	18.2		875		F
CC-7	18.8		900		D
CC-5	18.8		900		F
CC-12	18.8		900		P
CC-13	18.8		900		P
CC-6	19.3		925		P
CC-11	19.3		925		P
CC-8	18.8		900	1" Polished	D
CC-9	19.3		925	Bullet	D

D-ductile deformation
F-threshold of failure
P-penetration

TABLE B.14

FALLING WEIGHT TEST RESULTS
BEAMS SPECIMENS - SIMPLY SUPPORTED

Beam Span, in.	Speci-men No.	Drop Height ft.	Falling Weight, lbs.	Energy, ft-lbs.	Failure (1)	Comments
	Uncoated Polycarbonate, 0.310" Thickness					
3.10(10:1)	1B	4.76	10.50	50	D	
	2B	5.24	10.50	55	D	
	3B	6.19	10.50	65	D	
	4B	7.14	10.50	75	D	
1.86(6:1)	5B	7.14	10.50	75	D	
	15B	7.14	10.50	75	D	
	16B	7.14	10.50	75	D	
	11B	7.62	10.50	80	F	
	12B	7.62	10.50	80	D	
	14B	8.10	10.50	85	F	
	7B	8.10	10.50	85	D	
	10B	8.10	10.50	85	P	
	13B	8.10	10.50	85	F	
	30B	8.10	10.50	85	F	
	31B	8.10	10.50	85	F	
	9B	8.33	10.50	87.5	F	
	8B	8.57	10.50	90	F	
	6B	8.57	10.50	90	F	
	Coated Polycarbonate, 0.310" Thickness					
3.10(10:1)	19B	2.00	2.00	4.00	D	Coated Side Down
	21B	2.00	2.00	4.00	D	
	22B	2.25	2.00	4.50	D	
	20B	2.50	2.00	5.00	P	
	18B	1.00	5.54	5.54	P	
	17B	2.71	5.54	15	P	

(1) D = Ductile Deformation
F = Failure - Visible Crack; Beam Held Together
P = Penetration - Beam Split in Two

TABLE B.15

FALLING WEIGHT TEST RESULTS
BEAM SPECIMENS - SIMPLY SUPPORTED

T-38 Instructor's Windshield Material Evaluation

Specimen Number	Drop Height ft.	Falling Weight lbs.	Energy ft.-lbs.	Failure Type
Stretched Acrylic .92 x 6.44 x .46 inch beam - 2.76" Span				
1A	1.44	3.48	5.0	D
1A	2.87		10.0	S
2A	2.16		7.5	D
2A	2.59		9.0	D
2A	2.87		10.0	D
2A	3.45		12.0	S
3A	3.16		11.0	S
4A	2.87		10.0	S
5A	2.59		9.0	D
5A	2.73		9.5	S
6A	2.87		10.0	S
Commercial G.E. Lexan 1.00 x 7.0 x .5 inch beam - 3.00" Span				
ZC-2	15.08	8.88	134	D
ZC-4	7.87	18.14	143	D
ZC-5	7.87	18.14	143	D
ZC-3	9.44	18.14	171	D (pushed through supports)

D = ductile deformation
F = threshold of failure
P = penetration
S = shatter

TABLE B.16

NOTCHED IZOD AND NOTCHED CHARPY TEST RESULTS

NOTCHED IZOD TEST RESULTS

0.125 inch material (sheet) thickness

Specimen	Material Condition	Impact Strength (ft-lb/inch of notch)
137	As received	18.8
138	"	16.7
139	"	18.0
140	"	17.4
141	"	17.2
Mean (Std. Dev.)		17.6 (0.81)
96	Coated	1.44
97	"	1.60
98	"	1.51
99	"	1.53
100	"	1.53
Mean (Std. Dev.)		1.52 (0.057)
175	105°C for 2 hr.	2.55
176	"	2.65
177	"	2.21
185	"	2.44
186	"	2.98
Mean (Std. Dev.)		2.57 (0.28)
0.310 inch material (sheet) thickness		
127	As received	1.50
128	"	1.45
129	"	1.56
130	"	1.64
131	"	1.50
Mean (Std. Dev.)		1.53 (0.073)
132	Coated	1.34
133	"	1.27
134	"	1.31
135	"	1.31
136	"	1.31
Mean (Std. Dev.)		1.31 (0.025)
187	125°C for 2 hr.	1.25
188	"	1.37
189	"	1.42
190	"	1.38
191	"	1.48
Mean (Std. Dev.)		1.38 (0.085)

TABLE B.16 (continued)

NOTCHED CHARPY TEST RESULTS

0.125 inch material (sheet) thickness

78	As received	17.1	
79	"	16.7	
80	"	17.2	
81	"	16.7	
82	"	17.1	
Mean (Std. Dev.)		17.0	(0.24)
168	Coated	1.93	
169	"	1.98	
170	"	1.95	
171	"	1.98	
172	"	1.98	
Mean (Std. Dev.)		1.96	(0.023)
180	105°C for 2 hr.	2.13	
181	"	2.30	
182	"	3.02	
183	"	2.28	
184	"	2.22	
Mean (Std. Dev.)		2.39	(0.36)

0.310 inch material (sheet) thickness

142	As received	1.96	
143	"	2.06	
144	"	1.97	
145	"	2.02	
146	"	2.01	
Mean (Std. Dev.)		2.00	(0.040)
156	Coated	1.76	
157	"	1.77	
158	"	1.75	
159	"	1.79	
160	"	1.77	
Mean (Std. Dev.)		1.77	(0.015)
192	125°C for 2 hr.	1.81	
193	"	1.80	
194	"	1.78	
195	"	1.81	
196	"	1.81	
Mean (Std. Dev.)		1.80	(0.013)

TABLE B.17

THREE POINT FLEXURE TEST RESULTS

16/1 span/depth ratio - simply supported

Specimen Number	Specimen Material	Strain Rate (min.$^{-1}$)	2% Secant Stiffness (lb./in.)	2% Secant Modulus (lb./in.^{2})	Ultimate Stress (lb./in.^{2})	Energy to Ultimate (in.-lb.)
106	.125 As received	.01	159	330,000	17,520	9.69
107	"	"	156	323,500	17,340	9.69
108	"	"	156	323,700	17,500	9.64
109	"	"	164	338,200	17,470	9.50
110	"	"	164	337,300	17,580	9.57
Mean(Std. Dev.)			160(4.0)	330,500(7100)	17,480(90)	9.62(.08)
86	.125 Coated	.01	157	322,400	18,350	9.76
87	"	"	155	314,900	17,820	9.31
88	"	"	162	332,900	18,480	9.92
89	"	"	155	319,300	17,940	9.37
90	"	"	155	318,300	17,780	9.20
Mean(Std. Dev.)			157(3.0)	321,600(6900)	18,070(320)	9.51(.31)
112	.125 As received	200.	184	379,500	22,170	13.1
113	"	"	169	348,800	22,650	13.5
114	"	"	170	350,100	23,160	13.4
115	"	"	180	370,600	23,210	13.8
116	"	"	176	355,900	22,180	13.0
Mean(Std. Dev.)			176(6.4)	361,000(13,500)	22,670(510)	13.4(.32)
91	.125 Coated	200.	172	353,200	21,690	12.3
92	"	"	167	343,200	20,660	11.2
93	"	"	161	331,100	21,530	12.1
94	"	"	167	339,200	21,340	12.1
95	"	"	169	346,800	21,450	11.9
Mean(Std. Dev.)			167(4.0)	342,700(8300)	21,330(400)	11.9(.43)
46	.310 As received	.01	426	352,500	17,030	146
49	"	"	433	358,500	17,740	155
56	"	"	438	363,300	17,610	157
57	"	"	433	358,800	17,750	156
58	"	"	452	374,800	17,780	152
Mean(Std. Dev.)	"	"	436(9.7)	361,600(8300)	17,580(320)	153(4.4)
27	.310 Coated	.01	435	360,600	17,600	153
28	"	"	427	353,500	17,600	151
33	"	"	422	349,600	17,700	150
36	"	"	427	354,100	17,700	150
37	"	"	422	350,000	17,900	150
Mean(Std. Dev.)			427(5.3)	353,600(4400)	17,700(120)	151(1.3)
51	.310 As received	200.	483	404,400	20,940	198
52	"	"	480	397,000	20,180	189
53	"	"	480	397,700	20,650	188
54	"	"	504	417,100	20,460	191
55	"	"	484	401,200	20,620	187
Mean(Std. Dev.)			486(10.1)	403,500(0200)	20,570(280)	191(4.4)
31	.310 Coated	200.	487.	403,100	20,860	195
32	"	"	506.	419,200	20,980	190
34	"	"	487.	403,300	21,130	190
35	"	"	479.	396,700	21,030	187
Mean(Std. Dev.)			490(11.5)	405,600(9600)	21,000(110)	191(3.3)

*USGPO: 1984-759-062-694

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